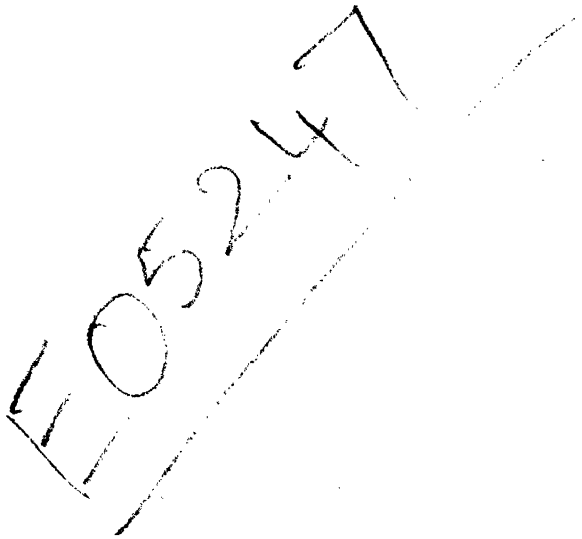
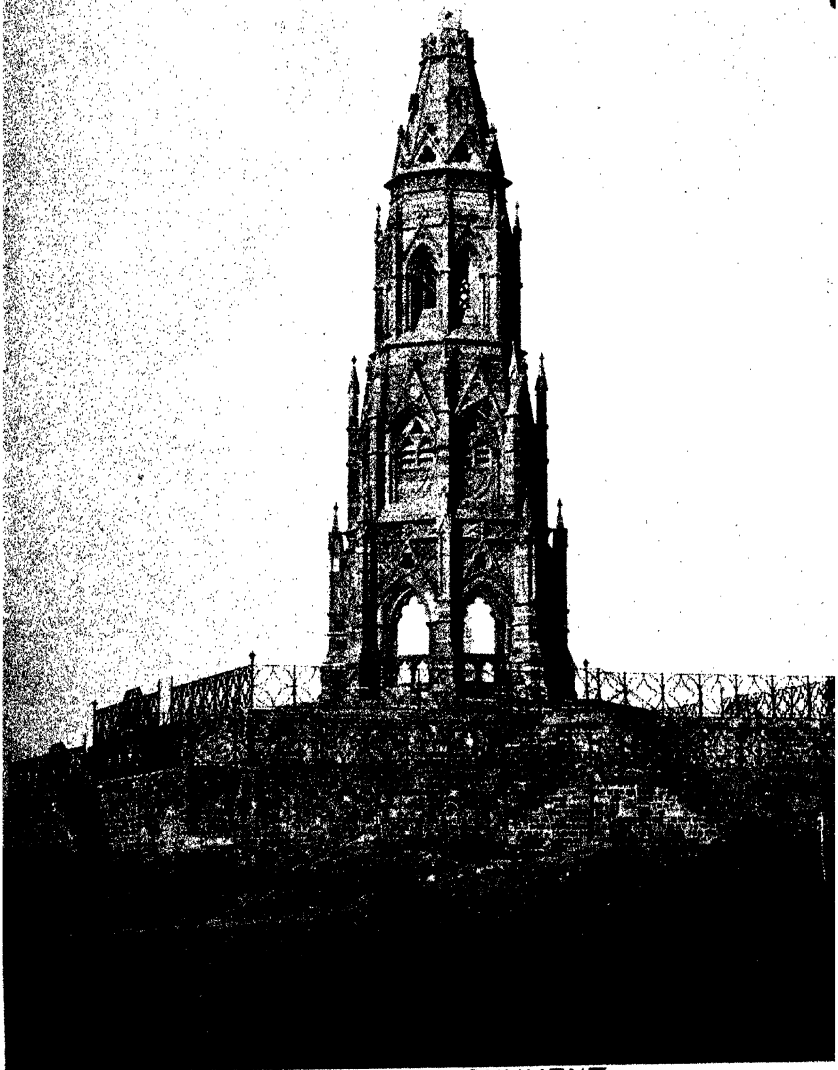

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NAWAB SALAR JUNG BAHADUR.



DELHI MEMORIAL MONUMENT.

PROFESSIONAL PAPERS

INDIAN ENGINEERING.

[SECOND SERIES.]

EDITED BY

MAJOR A. M. LANG, R.E.,

PRINCIPAL, THOMASON C. E. COLLEGE, ROORKEE.

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JAMES JOHNSTON, SUPERINTENDENT.

PREFACE TO VOL. IV.

With the simultaneous issue of Quarterly No. XVIII. and the Extra No. XVIIIA., the Fourth Volume of the Second Series of the Professional Papers of Indian Engineering is completed: forming the 11th Volume of these papers, which has been published since their commencement in 1863.

The present Volume contains forty-three Articles on a variety of subjects connected with Engineering in India: most departments of the profession being represented. *Eleven* papers deal with Canals, Reservoirs, Rivers, or Hydraulic Engineering of some sort: Railway subjects occupy *five* papers: *four* illustrate designs for large Buildings: *five* treat of the manufacture or testing of Cements: *four* are devoted to Building Materials: *two* to Instruments: *seven* deal with Mathematical investigations connected with matters of Engineering: and the remaining *five* relate to isolated, miscellaneous, professional questions.

The longest and most important paper in this Volume is that furnished by Capt. A. Cunningham, R.E., on the Hydraulic Experiments conducted by him in the winter of 1874-75. These Experiments—now about to be renewed—promise to be the most complete yet undertaken, and the most useful for Canal Engineers in this country: as they are in the hands of an officer of the highest mathematical ability, and eminently qualified for careful and accurate experiment: who, moreover, having studied and compared the modes of operation and the records of results of the latest workers in this branch of research, can copy what was most successful and avoid what was unsatisfactory in their working, and has at hand in the regular

channels, both in masonry and earth, of the Solani aqueduct, a body of water in uniform motion, and as such far more suitable for experiment and for *practical* results useful to Indian Canal Engineers, than the *very* small channels of MM. Darcy and Bazin, and the vast rivers on which Captain Humphreys and Lieutenant Abbot, and also M. Revy experimented.

The Bengal famine of 1874 made large demands on the Engineering resources of the country; and in connection with these, three interesting papers were communicated to this journal: of which, that on the Durbungah Railway merits especial notice, as illustrating the rapidity with which a narrow-gauge railway of forty miles in length can be constructed on new ground, and far from the base of supplies: an interesting problem in connection, not only with the exigencies of a famine, but also with military operations.

The question of railways for the Himalaya, or other lofty mountains, in our Indian possessions must before long claim the attention of Indian Engineers; and as a commencement of discussions on this subject, the paper on "A Mountain Railway for the Nilgiri Hills" will well repay perusal.

The increase of attention to the subject of Cements and Mortars within the last few years in this country is remarkable, and its effects are plainly visible in the improved quality of building work in the P. W. D. Mr. Dejoux's experiments in Calcutta have been conducted on a large scale, and have been noticed in previous numbers of this publication: in this Volume the extensive researches of Surgeon-Major Nicholson at Bangalore are described at some length, and afford a valuable contribution to our knowledge of the limes and cements of the Southern Presidency.

The first number of the next (No. V.) Volume will be issued in January, 1876: the terms of subscription, &c., continue as at present.

A. M. L.

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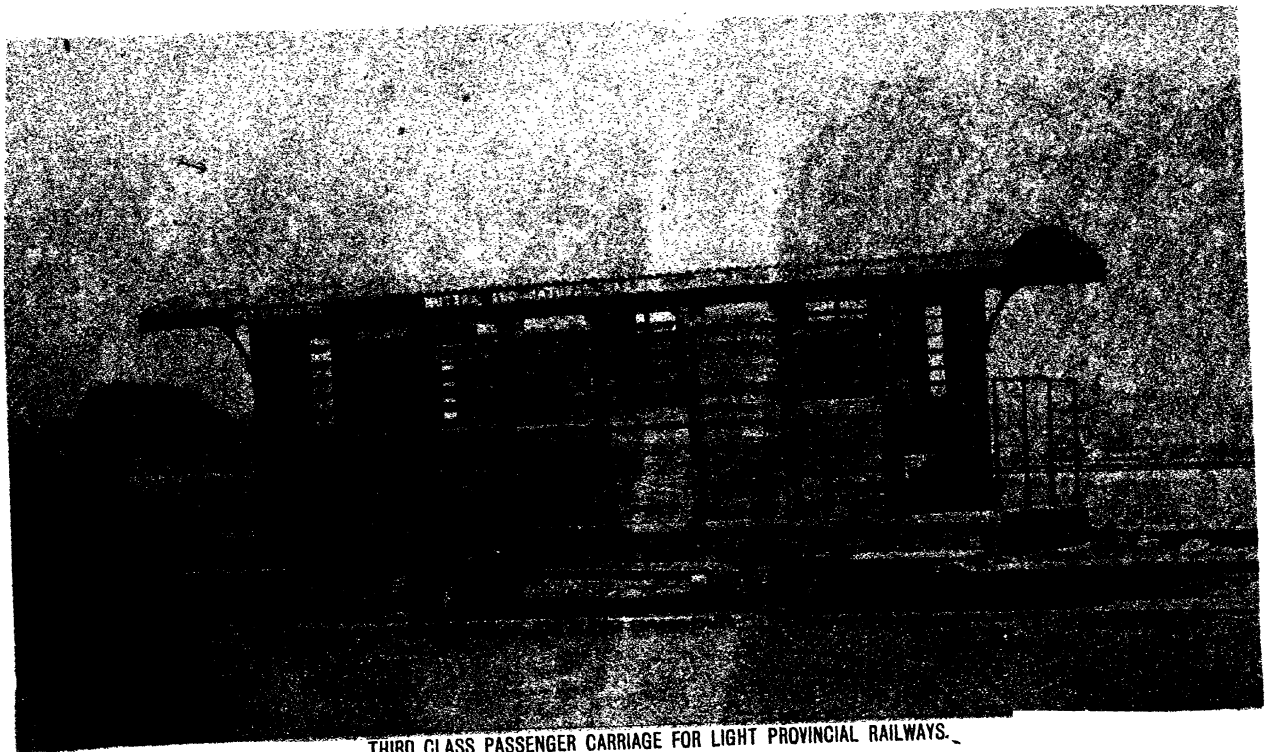
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THIRD CLASS PASSENGER CARRIAGE FOR LIGHT PROVINCIAL RAILWAYS.

No. CXXXVIII.

PASSENGER CARRIAGES FOR LIGHT (PROVINCIAL) RAILWAYS.

[*Vide* Photograph].

The Government of the North-Western Provinces have embarked in the interesting experiment of making Light Provincial Railways for the especial accommodation of Native traffic: part of the capital required is being supplied by native Mahajuns, and others, under a modified guarantee of 4 per cent. per annum; thus giving those who are to use the railway for the conveyance of their goods, a direct interest in supplying it with traffic. These railways act as feeders to the main lines, and will be gradually introduced all over the Province, wherever there is traffic enough, and where the residents will come forward and help themselves, by subscribing towards the capital necessary. In a great many places the cost of keeping up the railway will be more than met by the receipts, but in other cases where the receipts at first may be deficient, it does not follow that the Province will lose the money, for it will be less expensive to keep up such a railway than keep in good order a pucka road; that is, the cost of keeping up a pucka road will be more than the deficiency on a railway in a district where a good pucka road would be warranted by the traffic. The first line selected is between Muttra and Háthras, and the general principles which have guided the Government are as follows:—

I. In designing the vehicles and in the working of the traffic, the wants and conveniences of the native public are to be specially attended to.

II. In constructing the railway, the charges to capital are to be limited to the strict requirements necessary for strength, durability and convenience.

III. In making the railway, the charges to revenue are to be kept as low as possible consistent with the safety of the public traffic.

IV. The standard dimensions of the Metre Gauge State Railways to be observed, in order to admit of the future interchange of through traffic and rolling stock.

V. The through speed to be limited to ten miles per hour, including any stoppage under 15 minutes, but excluding any stoppage longer than 15 minutes.

VI. The maximum weight per wheel to be limited to 2½ tons.

In designing the rolling stock, the objects aimed at have been, to have as few varieties of vehicles as possible: for this purpose the carriages for the passenger traffic have been limited to two—a third and first class, or lower and upper class; and these two carriages are the same in every respect, except the internal arrangements, which will be described further on. The brake van is not a separate vehicle, but is part of a third class carriage.

For the goods traffic, the type of vehicle is also limited to two—a low sided goods wagon and a covered goods. These latter are to be in every respect the same as those on use in the State Railways, except that the roof of the covered goods wagon is made of No. 18 gauge galvanized corrugated iron.

In the present Number is given a Photograph of the sample lower class carriage made up at the Canal Foundry and Workshops, Roorkee: the whole of this carriage including springs, wheels, axle-boxes, &c., have been made at Roorkee. The framing and outside planking are of teak, the seats and flooring of deodar, and the inner roof of *Pinus excelsa*. The outer roof is of No. 18 gauge corrugated galvanized iron, which makes the only permanent water-tight roof.

It will be seen from the view given, that the entrances are at the ends, and that the outer roof comes over these ends, protecting them and the end doors from the sun and rain; there is also at each end a small platform enabling a person to get from one carriage to another when the train is in motion; this allows the collection of the tickets before the train arrives at its destination, and allows communication between the conductor or guard, the engine driver, and the passengers. Inside the lower class passenger carriage, there is a platform on each side, with a

passage between, 1′ 4″ wide. The platform is raised 1′ 5″ above the floor, so as to allow space for the passengers to stow their bundles in. At every 5 feet there is a back going across the platform, so that the passengers can lean against it: this also prevents crushing. Each compartment will hold four passengers, and as there are 3½ compartments on each side, the carriage will hold 28 passengers. There is also at each end on the platform a folding-down seat, which will accommodate two more passengers. The wheels are 10 feet apart from centre to centre, and the entire length of the carriage is 22′ 4½″. The carriage is provided with the combined central buffer and draw bar, with self-acting coupling hook of the same pattern as those on the State Narrow-Gauge Railways.

NAWAB SALAR JUNG BAHADUR.

No. CXXXIX.

DESIGN FOR THE MAHARAO RAJAH'S STATION AT ULWAR.

[*Vide* Plates I. to V.]

By Teekaram, *Head Draftsman, Engineer-in-Chief's Office, Rajpootana State Railway, Delhi District.*

Description.

Ulwar is the 12th Station on the Delhi District of the Rajpootana State Railway, and 97 miles from Delhi.

It is a second class station, and situated about a mile from the city. The buildings consist of a passenger station, goods shed, tank house and other minor and miscellaneous buildings, and the style of architecture throughout is modern.

In addition to these, it was first proposed to erect a small private station for His Highness the Maharaja, consisting of two rooms and a covered platform for his carriage and private party.

However His Highness and Council decided to erect a much more important building, and one more suitable to his rank: accordingly a sum of Rs. 30,000 was voted towards its erection, and the design left open to competition; Rs. 500 being offered for the successful competitor.

The premium was awarded, to the design submitted by Teekarám, which was selected and approved on the 8th May, 1873: but the present design as shown in the accompanying drawings, differs somewhat from that originally proposed: the Maharao Rajah after selecting the latter, desiring to have a larger building and more outside accommodation.

The design is in the Hindoo style of architecture, the details having been taken from some of the best known and most admired types; and it

(including the ornamental work;) to be finished with an enamelled surface to imitate polished marble.

Flooring.—To consist of sandstone flagging, of an ornamental pattern; the several pieces to vary in shape and color, so as to contrast one with the other; the whole to be laid with the finest possible joints in the best mortar, over 6 inches of terracing.

Doors.—To be of the best teak wood, with a veneering of ornamental brass plates, screwed to the woodwork, and glazed with plate glass, let into plough grooves sunk in the woodwork.

Private enclosure.—The masonry to be of the best rubble in lime mortar, coated with enamel plaster carefully finished.

Care to be taken that through bond stones extending the full thickness of the wall should occur at distances of not more than 5 feet apart in every course. The flat superficies to be of plain ashlar, neatly chisel-dressed, and properly squared, the mouldings to be accurately cut, and the arises to be sharp and true; the carved work to be correctly wrought, and all ornaments to represent correct types of the style of architecture in which the building is designed. The whole of the masonry to be laid in the very best mortar procurable.

Roofing.—The rooms and verandah in the station building (save the central hall, which is to be domed) to be vaulted or arched as shown in the section, *(Plate* IV.,*)* the arches to be of the best pucka bricks laid in lime mortar, built in concentric rings, and plastered internally.

ABSTRACT ESTIMATE.

NAWAB SALAR JUNG BAHADUR.

c. ft.		Rs.
3,004	Concrete in foundation, at Rs. 18 per 100, ...	541
26,187	Stone masonry, at Rs. 25 per 100, ...	6,547
2,562	Dome including centring, at Rs. 60 per 100, ...	1,537
674	Arching, at Rs. 30 per 100, ...	202
8,215	Rough sandstone at Rs. 2 per foot,...	16,430
s. ft.		
9,098	Dressing and carving, &c., at Rs. 2 per foot, ...	18,196
c. ft.		
450	Marble stone, at Rs. 10 per foot, ...	4,500
s. ft.		
891	Dressing and carving, &c., at Rs. 8 per foot, ...	3,128
19,008	Plastering, including ornamental works, at Rs. 10 per 100, ...	1,900
1,000	Flooring of rooms, at Rs. 2 per foot, ...	2,000
	Carried over, ...	56,001

		Rs.
	Brought forward, ...	55,001
c. ft.		
1,600	Sandstone flooring, at Rs. 30 per 100, ...	480
400	Doors, at Rs. 4 per foot, ...	1,600
mds. srs.		
236 36	Ironwork in girders, at Rs. 14 per maund, ...	3,317
No.		
2	Gates for private entrance, at Rs. 200 each, ...	400
3	*Kalas* or pinnacles, at Rs. 200 each, ...	600
1	Roof of ventilator, at Rs. 30, ...	30
s. ft.		
1,397	Terrace roofing of shed, at Rs. 10 per 100, ...	140
	Total, ...	61,568
	Contingencies, at Rs. 5 per cent., ...	3,078
	Grand Total, Rs., ...	64,646

No. CXL.

RAJBAHA VELOCITIES AND DISCHARGES.

Prepared by MAJOR A. M. BRANDRETH, R.E., *and recomputed for the Punjab Irrigation Department under superintendence of* CAPT. ALLAN CUNNINGHAM, R.E.

THESE Tables have been computed from the following data and formulæ :—

Data,—

Channel trapezoidal—

Sides slopes 1·5 to 1, $\left(i.\ e.,\ \frac{1{\cdot}5 \text{ horizontal}}{1 \text{ vertical}}\right)$.

b = bed width *in feet.*

d = depth of water *in feet.*

f = fall of channel in 5000 feet *in feet.*

Required,—

A = Area *in square feet.*

R = Hydraulic Mean Depth *in feet.*

V = Mean velocity *in feet per second.*

D = Discharge *in cubic feet per second*

C = Co-efficient taken.

Formulæ used in computation.

$$A = (b + \tfrac{3}{2} d)\, d.$$

$$R = \frac{A}{b + 3{\cdot}606 d}$$

$$V = \sqrt{\frac{2R}{7 + 1{\cdot}7066\ R}} \cdot \sqrt{f}.$$

$$D = AV.$$

$$C = 1 \div \sqrt{\cdot 00008533 + \frac{\cdot 00035}{R}}$$

The formula for V is modified from one given in "Professional Papers on Indian Engineering," First Series, No. CXCVII, (by the late Lieut.-Col. J. C. Anderson, R.E.,) 4th type of Table I,

$$\frac{RI}{U^2} = \cdot 00035 \left(\cdot 2438 + \frac{1}{R}\right)$$

as suitable (on Bazin's authority) *for channels whose "Bed and sides are of earth."* The form here given is more suited for computation of the Tables.

The co-efficient C (which forms the last column of the Tables) is simply the square root of the reciprocal of $\cdot 00035 \left(\cdot 2438 + \frac{1}{R}\right)$, so that $U = C\sqrt{RI}$,

whence $V = C \cdot \sqrt{R \times \frac{f}{5000}}$.

The Tables were originally prepared by Major A. M. Brandreth, R.E. The new Edition has been *entirely recomputed* by two independent computers.

The numbers in the columns of "Areas" are exact. The numbers in the columns of R, V, D, C were in every case computed to at least one more decimal than is now printed, and the first differences were then examined by the writer himself. These first differences were so regular, that the writer believes that the published values may be depended on to the last figure.

A. G.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5000 feet.																Co-efficient taken.
			2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side Slopes, 1·5 to 1. Depth of water, 1·0 feet.																			
3	4·5	·681	·674	3·03	·630	2·84	·583	2·63	·533	2·40	·477	2·15	·413	1·86	·337	1·52	·238	1·07	40·35
4	5·5	·723	·710	3·91	·666	3·66	·615	3·38	·563	3·10	·504	2·77	·436	2·40	·357	1·95	·252	1·39	41·91
5	6·5	·755	·742	4·82	·693	4·51	·640	4·16	·586	3·80	·524	3·41	·454	2·95	·371	2·41	·262	1·70	42·70
6	7·5	·780	·764	5·73	·715	5·36	·661	4·96	·604	4·53	·541	4·05	·468	3·51	·382	2·87	·270	2·03	43·29
7	8·5	·801	·783	6·66	·732	6·22	·678	5·76	·619	5·26	·554	4·71	·480	4·08	·392	3·33	·277	2·35	43·76
8	9·5	·818	·798	7·58	·746	7·09	·692	6·57	·631	5·99	·565	5·36	·489	4·64	·399	3·79	·282	2·68	44·15
9	10·5	·833	·812	8·52	·759	7·97	·702	7·38	·642	6·74	·574	6·03	·497	5·22	·406	4·26	·287	3·01	44·47
10	11·5	·846	·823	9·46	·770	8·85	·712	8·19	·650	7·48	·582	6·69	·504	5·79	·411	4·73	·291	3·34	44·74
11	12·5	·856	·832	10·40	·778	9·73	·720	9·00	·658	8·22	·589	7·36	·510	6·37	·416	5·20	·294	3·68	44·97
12	13·5	·865	·841	11·35	·786	10·61	·727	9·81	·664	8·96	·594	8·02	·514	6·94	·420	5·67	·297	4·01	45·17
13	14·5	·873	·847	12·29	·792	11·49	·733	10·63	·670	9·71	·599	8·69	·519	7·52	·424	6·14	·300	4·34	45·34
14	15·5	·880	·854	13·23	·798	12·37	·739	11·45	·675	10·46	·604	9·36	·523	8·10	·427	6·62	·302	4·68	45·50
15	16·5	·886	·859	14·17	·803	13·25	·743	12·27	·679	11·20	·607	10·02	·526	8·68	·429	7·09	·304	5·01	45·64
16	17·5	·892	·864	15·12	·808	14·14	·748	13·09	·683	11·95	·611	10·69	·529	9·26	·432	7·56	·306	5·35	45·76
17	18·5	·897	·869	16·07	·813	15·02	·752	13·91	·687	12·70	·614	11·36	·532	9·84	·434	8·03	·307	5·68	45·87
18	19·5	·902	·873	17·02	·816	15·91	·756	14·73	·690	13·46	·617	12·04	·535	10·42	·436	8·51	·309	6·02	45·97
19	20·5	·906	·877	17·97	·820	16·80	·759	15·55	·693	14·21	·620	12·71	·537	11·00	·438	8·99	·310	6·35	46·05
20	21·5	·910	·880	18·92	·823	17·68	·762	16·37	·696	14·96	·622	13·38	·539	11·58	·440	9·46	·311	6·69	46·13

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5000 feet.																Co-efficient taken.
			2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Depth of water, 1·5 feet.																			
3	7·875	·935	·902	7·10	·843	6·64	·781	6·15	·713	5·62	·638	5·02	·552	4·35	·451	3·55	·319	2·51	46·65
4	9·375	·995	·954	8·93	·892	8·36	·826	7·74	·754	7·07	·675	6·32	·584	5·48	·477	4·46	·337	3·16	47·83
5	10·875	1·045	·997	10·84	·932	10·14	·863	9·39	·788	8·57	·705	7·67	·611	6·64	·499	5·42	·353	3·83	48·78
6	12·375	1·084	1·03	12·75	·963	11·92	·892	11·04	·815	10·08	·729	9·02	·631	7·81	·515	6·37	·364	4·51	49·50
7	13·875	1·118	1·06	14·69	·988	13·74	·917	12·72	·838	11·62	·749	10·40	·649	9·00	·530	7·35	·375	5·20	50·11
8	15·375	1·146	1·08	16·66	1·01	15·56	·937	14·41	·856	13·16	·766	11·78	·663	10·20	·541	8·33	·383	5·89	50·60
9	16·875	1·170	1·10	18·61	1·03	17·40	·955	16·11	·872	14·72	·780	13·16	·675	11·40	·551	9·31	·390	6·58	51·00
10	18·375	1·192	1·12	20·60	1·05	19·26	·971	17·84	·887	16·29	·793	14·57	·687	12·61	·561	10·30	·397	7·29	51·36
11	19·875	1·211	1·14	22·60	1·06	21·13	·985	19·58	·899	17·87	·804	15·99	·697	13·84	·569	11·30	·402	7·99	51·68
12	21·375	1·228	1·15	24·60	1·08	23·00	·997	21·32	·910	19·46	·814	17·41	·705	15·07	·576	12·30	·407	8·70	51·96
13	22·875	1·242	1·16	26·60	1·09	24·87	1·01	23·04	·920	21·04	·823	18·82	·712	16·30	·582	13·30	·411	9·41	52·19
14	24·375	1·255	1·17	28·62	1·10	26·74	1·02	24·79	·928	22·62	·830	20·23	·719	17·52	·587	14·31	·415	10·12	52·40
15	25·875	1·267	1·18	30·61	1·11	28·64	1·02	26·50	·936	24·21	·837	21·66	·725	18·75	·592	15·31	·418	10·83	52·59
16	27·375	1·278	1·19	32·63	1·11	30·50	1·03	28·25	·943	25·81	·843	23·09	·730	20·00	·596	16·32	·422	11·54	52·77
17	28·875	1·288	1·20	34·68	1·12	32·40	1·04	30·03	·950	27·42	·850	24·53	·736	21·24	·601	17·34	·425	12·26	52·93
18	30·375	1·297	1·21	36·69	1·13	34·29	1·05	31·77	·955	29·01	·855	25·96	·740	22·48	·604	18·35	·427	12·98	53·07
19	31·875	1·305	1·21	38·70	1·14	36·18	1·05	33·53	·961	30·62	·859	27·39	·744	23·72	·607	17·35	·430	13·69	53·19
20	33·375	1·313	1·22	40·68	1·14	38·05	1·06	35·28	·966	32·23	·864	28·83	·748	24·96	·611	20·34	·432	14·41	53·30

Mean Width.	Area of wetted section.	Mean Hydraulic depth.	Fall of Channel in 5000 feet.																Co-efficient values.
			2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Depth of water, 2 feet.																			
3	12	1·173	1·11	13 28	1·04	12·43	·96	11·51	·876	10·51	·783	9·40	·678	8·14	·554	6·64	·393	4·70	51·09
4	14	1·248	1·17	16·35	1·09	15·30	1·01	14·17	·924	12·94	·826	11·56	·716	10·02	·584	8·18	·413	5·79	52·29
5	16	1·310	1·22	19 50	1·14	18·24	1·06	16 88	·964	15·42	·862	13·79	·747	11·95	·609	9·75	·431	6·90	53·26
6	18	1·362	1·26	22·70	1·18	21·24	1·03	19·67	·997	17·95	·892	16·06	·773	13·91	·631	11·35	·446	8·03	54·05
7	20	1·407	1·30	25·96	1·21	24 28	1·12	22 48	1·03	20·51	·917	18 34	·795	15·90	·649	12·98	·459	9·17	54·71
8	22	1·446	1·33	29·24	1·24	27·35	1·15	25 32	1·05	23·12	·940	20·67	·814	17·91	·664	14·62	·470	10·34	55·27
9	24	1·480	1·36	32·54	1·27	30·46	1·17	28 20	1·07	25·74	·959	23·02	·831	19·93	·678	16·27	·479	11·51	55·75
10	26	1·510	1·38	35·88	1·29	33·57	1·20	31·08	1·09	28·38	·976	25·38	·845	21·97	·690	17·94	·488	12·69	56·16
11	28	1·537	1·40	39·23	1·31	36·68	1·21	33·96	1·11	31·03	·991	27·75	·858	24·02	·700	19·61	·495	13·87	56·52
12	30	1·561	1·42	42·60	1·33	39·84	1·23	36·87	1·12	33·68	1·00	30·13	·870	26·03	·710	21·30	·502	15·06	56·84
13	32	1·583	1·44	45·98	1·34	43·01	1·24	39·80	1·14	36·35	1·02	32·51	·880	28·16	·718	23·00	·508	16·26	57·12
14	34	1·602	1·45	49·37	1·36	46·18	1·26	42·76	1·15	39·03	1·03	34·91	·889	30·24	·726	24·68	·513	17·45	57·37
15	36	1·620	1·47	52·78	1·37	49·39	1·27	45 72	1·16	41·71	1·04	37·31	·898	32·32	·733	26·39	·518	18·66	57·60
16	38	1·637	1·48	56 18	1 38	52·58	1·28	48·68	1·17	44·41	1·05	39 72	·906	34·41	·739	28·09	·523	19·86	57·81
17	40	1·652	1·49	59·60	1·40	55·78	1·29	51·64	1·18	47·12	1·05	42·14	·913	36·51	·745	29·80	·527	21·07	58·00
18	42	1·665	1·50	63·04	1·40	58·98	1·30	54·62	1·19	49·83	1·06	44·57	·919	38 61	·750	31·52	·531	22·28	58·17
19	44	1·678	1·51	66·48	1·41	62·19	1·31	57 60	1·19	52·54	1·07	47·00	·925	40·72	·755	32·24	·534	23·50	58·33
20	46	1·690	1·52	69·93	1·42	65·40	1·32	60 58	1·20	55·28	1·08	49·44	·931	42·83	·760	34·97	·537	24·72	58·48

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5000 feet.																Co-efficient taken.
			2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Depth of water, 2·5 feet.																			
3	16·875	1·404	1·30	21·85	1·21	20·45	1·12	18·93	1·02	17·28	·916	15·46	·793	13·37	·648	10·93	·458	7·73	54·67
4	19·375	1·488	1·36	26·41	1·28	24·70	1·18	22 86	1·08	20 87	·964	18 68	·834	16·16	·682	13·20	·482	9·34	55·86
5	21·875	1·580	1·42	31·04	1·33	29·05	1·23	26·88	1·12	24·54	1·00	21·96	·869	19·01	·710	15·52	·502	10·98	56·84
6	24·375	1·623	1·47	35·78	1·37	33·52	1·27	30·99	1·16	28·30	1·04	25·30	·899	21·91	·734	17·89	·519	12·65	57·65
7	26·875	1·678	1·51	40·61	1·41	38·00	1·31	35·15	1·19	32·10	1·07	28 69	·925	24·86	·755	20·30	·534	14·35	58·34
8	29·375	1·726	1·55	45·47	1·45	42·54	1·34	39·37	1·22	35·95	1·09	32·13	·948	27 85	·774	22·74	·547	16·06	58·92
9	31·875	1·768	1·58	50·37	1·48	47·11	1·37	43 63	1·25	39 82	1·12	35·60	·968	30 86	·790	25·18	·559	17·80	59·42
10	34·375	1·807	1·61	55·30	1·51	51·73	1·39	47·92	1·27	43·73	1·14	39·12	·986	33·89	·805	27 65	·569	19·56	59·86
11	36·875	1·842	1·64	60·31	1·53	56·40	1·42	52·24	1·29	47·67	1·16	42·66	1·00	36·95	·818	30·15	·578	21·33	60·26
12	39·375	1·873	1·66	65·32	1·55	61·11	1·44	56·58	1·31	51·64	1·17	46·21	1·02	40·02	·829	32·66	·586	23·10	60·62
13	41·875	1·902	1·68	70·35	1·57	65·82	1·46	60·93	1·33	55·63	1·19	49·76	1·03	43 09	·840	35·18	·594	24·88	60·74
14	44·375	1·927	1·70	75·39	1·59	70·53	1·47	65·30	1·34	59·61	1·20	53·31	1·04	46 17	·849	37·70	·601	26·66	61·22
15	46·875	1·951	1·72	80·44	1·61	75·25	1·49	69·68	1·36	63·63	1·21	56·89	1·05	49·28	·858	40·22	·607	28·44	61·46
16	49·375	1·973	1·73	85·52	1·62	79·99	1·50	74 08	1·37	67·64	1·23	60·47	1·06	52·39	·866	42·76	·612	30·24	61·68
17	51·875	1·993	1·75	90·63	1·63	84 76	1·51	78·50	1·38	71·66	1·24	64·07	1·07	55·51	·873	45·31	·617	32 03	61·90
18	54·375	2·012	1·76	95·75	1·65	89·56	1·53	82·92	1·39	75·69	1·25	67·63	1·08	58 64	·880	47·88	·622	33·84	62·10
19	56·875	2·030	1·77	100·90	1·66	94·36	1·54	87·37	1·40	79·74	1·25	71·32	1·09	61·78	·887	50·45	·627	35·66	62·28
20	59·375	2·046	1·79	106·04	1·67	99·20	1·55	91·84	1·41	83·82	1·26	74·99	1·10	64·94	·893	53 02	·631	37·49	62·45

Rod Readings.	Area of wetted section.	Mean Hydraulic Depth.	Fall of Channel in 5000 feet.																Co-efficient taken.
			2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Depth of water, 3 feet.																			
3	22·5	1·629	1·47	33·14	1·38	30·98	1·28	28·69	1·16	26·19	1·04	23·45	·902	20·30	·736	16·57	·521	11·72	57·73
4	25·5	1·721	1·54	37·37	1·44	36·82	1·34	34·09	1·22	31·11	1·09	27·85	·946	24·12	·772	19·69	·546	13·92	58·86
5	28·5	1·802	1·61	45·74	1·50	42·78	1·39	39·62	1·27	36·17	1·14	32·35	·983	28·04	·803	22·87	·567	16·17	59·81
6	31·5	1·873	1·66	52·23	1·55	48·86	1·44	45·23	1·31	41·30	1·17	36·95	1·02	31·97	·827	26·11	·586	18·48	60·62
7	34·5	1·936	1·71	58·82	1·59	55·03	1·48	50·96	1·35	46·51	1·21	41·61	1·04	36·02	·852	29·41	·603	20·80	61·31
8	37·5	1·993	1·75	65·51	1·63	61·28	1·51	56·74	1·38	51·79	1·24	46·31	1·07	40·13	·873	32·76	·618	23·16	61·91
9	40·5	2·044	1·79	72·30	1·67	67·60	1·55	62·58	1·41	57·15	1·26	51·11	1·09	44·27	·892	36·15	·631	25·56	62·44
10	43·5	2·090	1·82	79·09	1·70	73·99	1·57	68·47	1·44	62·55	1·29	55·94	1·11	48·42	·909	39·54	·643	27·97	62·90
11	46·5	2·132	1·85	85·93	1·73	80·45	1·60	74·40	1·46	67·98	1·31	60·81	1·13	52·64	·924	42·97	·653	30·40	63·31
12	49·5	2·170	1·88	92·81	1·76	86·92	1·62	80·39	1·48	73·42	1·33	65·69	1·15	56·88	·938	46·41	·663	32·84	63·68
13	52·5	2·204	1·90	99·75	1·78	93·40	1·65	86·43	1·50	78·86	1·34	70·56	1·16	61·11	·950	49·87	·672	35·28	64·01
14	55·5	2·236	1·92	106·73	1·80	99·87	1·67	92·46	1·52	84·36	1·36	75·48	1·18	65·34	·961	53·36	·680	37·74	64·31
15	58·5	2·266	1·94	113·72	1·82	106·35	1·68	98·51	1·54	89·91	1·38	80·44	1·19	69·62	·971	56·86	·687	40·22	64·58
16	61·5	2·293	1·96	120·70	1·84	112·90	1·70	104·55	1·55	95·45	1·39	85·38	1·20	73·90	·981	60·35	·693	42·69	64·85
17	64·5	2·318	1·98	127·71	1·85	119·45	1·72	110·62	1·57	100·97	1·40	90·33	1·21	78·20	·990	63·86	·699	45·16	65·06
18	67·5	2·342	2·00	134·79	1·87	126·09	1·73	116·75	1·58	106·52	1·41	95·31	1·22	83·51	·998	67·40	·705	47·66	65·27
19	70·5	2·364	2·01	141·90	1·88	132·75	1·74	122·89	1·59	112·14	1·42	100·32	1·23	86·86	1·01	70·95	·711	50·16	65·47
20	73·5	2·385	2·03	149·01	1·90	139·43	1·75	129·02	1·60	117·77	1·43	105·34	1·24	91·22	1·01	74·81	·716	52·67	65·65

Real Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5600 feet. 2·00 V	2·00 D	1·75 V	1·75 D	1·5 V	1·5 D	1·25 V	1·25 D	1·00 V	1·00 D	0·75 V	0·75 D	0·5 V	0·5 D	0·25 V	0·25 D	Co-efficient taken.
Depth of water, 3·5 feet.																			
3	28·875	1·848	1·64	47·36	1·53	44·30	1·42	41·00	1·30	37·42	1·16	33·50	1·00	28·99	·820	23·68	·580	16·75	60·35
4	32·375	1·947	1·71	55·49	1·60	51·90	1·48	48·05	1·36	43·87	1·21	39·24	1·05	33·96	·857	27·75	·606	19·62	61·42
5	35·875	2·035	1·78	63·82	1·66	59·69	1·54	55·25	1·41	50·44	1·26	45·13	1·09	39·07	·889	31·91	·629	22·57	62·34
6	39·375	2·114	1·84	72·29	1·72	67·65	1·59	62 61	1·45	57·13	1·30	51·11	1·12	44 26	·918	36·15	·649	25·55	63·13
7	42·875	2·184	1·89	80·86	1·77	75·68	1·63	70 06	1·49	63·93	1·33	57·20	1·16	49·52	·943	40·43	·667	28·60	63·81
8	46·375	2·248	1·93	89·55	1·81	83·80	1·67	77·58	1·53	70·81	1·37	63·35	1·18	54·86	·965	44·78	·683	31·67	64·42
9	49·875	2·306	1·97	98·35	1·85	92·02	1·71	85·24	1·56	77·76	1·39	69·53	1·21	60·25	·985	49·18	·697	34·76	64·93
10	53·375	2·358	2·01	107·23	1·88	100 29	1·74	92·89	1·59	84 76	1·42	75·79	1·23	65·65	1·00	53·62	·710	37·90	65 40
11	56·875	2·407	2·04	116·14	1·91	108·63	1·77	100·61	1 62	91·85	1·44	82·13	1·25	71·10	1·02	58·07	·722	41·06	65·83
12	60·375	2·451	2·07	125·10	1·94	117·07	1·80	108 37	1·64	98·96	1·47	88·51	1·27	76·62	1 04	62·55	·733	44·26	66·22
13	63·875	2·492	2·10	134·14	1·97	125·52	1·82	116·21	1·66	106·10	1·49	94·92	1·29	82·14	1·05	67·07	·743	47·46	66·37
14	67·375	2·530	2·13	143·24	1·97	134·01	1·84	124·11	1·68	113·26	1·50	101·33	1·30	87·72	1·06	71·62	·752	50·67	66·88
15	70·875	2·565	2·15	152·38	2·01	142·53	1·86	132·00	1·70	120·43	1·53	107·74	1·32	93·34	1·08	76·19	·760	53·87	67·16
16	74·375	2·598	2·17	161·54	2·03	151·13	1·88	139·91	1·72	127·69	1·54	114·24	1·33	98·99	1·09	80·77	·768	57·12	67·41
17	77·875	2·628	2·19	170·70	2·05	159·73	1·90	147·89	1·73	135·03	1·55	120·79	1·34	104·60	1·10	85·35	·775	60·39	67·64
18	81·375	2·656	2·21	179·92	2 07	168·37	1·92	155·91	1·75	142·33	1·56	127·29	1·35	110·20	1·11	89·96	·782	63·65	67·86
19	84·875	2·683	2·23	189·19	2·09	177·05	1·93	163·91	1·76	149·64	1·58	133·85	1·37	115·86	1·12	94·59	·788	66·92	68·07
20	88·375	2·708	2·25	198·49	2·10	185·71	1·95	171·92	1·78	156·95	1·59	140·43	1·37	121·52	1·12	99·25	·794	70·21	68·27

Flush Width	Area of cross section.	Mean Hydraulic depth.	2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		Coefficient taken.
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
DEPTH OF WATER, 4 FEET.																			
3	36	2·066	1·80	64·82	1·68	60·62	1·56	56·12	1·42	51·26	1·27	45·83	1·10	39·71	·900	32·41	·636	22·91	62·66
4	40	2·171	1·88	75·07	1·76	70·20	1·63	65·00	1·48	59·36	1·33	53·08	1·15	45·96	·938	37·53	·663	26·54	63·69
5	44	2·265	1·94	85·54	1·82	79·99	1·68	74·05	1·54	67·60	1·37	60·46	1·19	52·36	·972	42·77	·687	30·23	64·56
6	48	2·350	2·00	96·16	1·87	89·94	1·73	83 23	1·58	75·98	1·42	67·97	1·23	58 87	1·00	48 08	·708	33·98	65·33
7	52	2·427	2·06	106·91	1·92	100·02	1·78	92·56	1·63	84·53	1·45	75·61	1·26	65·47	1·03	53·46	·727	37·80	66·00
8	56	2·497	2·10	117·81	1·97	110·21	1·82	102·03	1·66	93·18	1·49	83·34	1·2)	72·13	1·03	58·91	·744	41 67	66·59
9	60	2·561	2·15	128·86	2·01	120·52	1·86	111·62	1·70	101·90	1·52	91·10	1·32	78 88	1·07	64·43	·759	45·55	67·12
10	64	2·620	2·19	140·03	2·05	130·94	1·90	121·28	1·73	110·68	1·55	98·94	1·34	85·70	1·09	70·02	·773	49·47	67·59
11	68	2·674	2·22	151·26	2·08	141·44	1·93	130·98	1·76	119·53	1·57	106 88	1·36	92·58	1·11	75·63	·786	53·44	68·01
13	72	2·725	2·26	162·54	2·11	152·01	1·96	140·74	1·79	128·49	1·60	114·90	1·38	99·50	1·13	81·27	·798	57·45	68·39
12	76	2·771	2·29	173·92	2·14	162·64	1·98	150·57	1·81	137·48	1·62	122·97	1·40	106·46	1·14	86·96	·809	61·48	68·74
14	80	2·814	2·32	185·34	2·17	173·36	2·01	160·48	1 83	146·49	1·64	131·06	1·42	113 44	1·16	92·67	·819	65·53	69·06
15	84	2·855	2·34	196·81	2·19	184·12	2·03	170·43	1·85	155 57	1·66	139·16	1·43	120·46	1·17	98·41	·828	69 58	69·35
16	88	2·892	2·37	208·33	2·21	194·90	2·05	180·40	1·87	164·68	1·67	147·31	1·45	127 51	1·18	104·17	·837	73·66	69·61
17	92	2·927	2·39	219·88	2·24	205·70	2·07	190·39	1·89	173·82	1·69	155·48	1·46	134·60	1·20	109·94	·845	77·74	69·85
18	96	2·961	2·41	231·50	2·26	216·52	2·09	200·45	1·91	182·98	1·71	163·68	1·48	141 70	1·21	115·75	·852	81·84	70·08
19	100	2·992	2·43	243·20	2·28	227·40	2·11	210·56	1·92	192·18	1·72	171·90	1·49	148 85	1·22	121·60	·859	85·95	70·31
20	104	3·021	2·45	254·94	2·29	238·27	2·12	220 69	1·94	201·45	1·73	180·13	1·50	156·00	1·23	127·47	·866	90·06	70 53

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5000 feet.																Co-efficient taken.
			2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
			Depth of water, 4·5 feet.																
3	43·875	2·282	1·96	85·78	1·83	80·25	1·69	74 28	1·55	67·83	1·38	60·63	1·20	52·47	·977	42·89	·691	30·34	64·72
4	48·375	2·391	2·03	98·30	1·90	91·96	1·76	85·14	1·61	77·74	1·44	69·52	1·24	60·13	1·02	49·15	·718	34·76	65·70
5	52·875	2·491	2·10	111·04	1·97	103·90	1 82	96·18	1·66	87·83	1·49	78·52	1·23	67·94	1·05	55·52	·742	39·26	66·55
6	57·375	2·581	2·16	123·99	2·02	116·02	1·87	107·41	1·71	98 06	1·53	87 71	1·32	75·91	1·08	61·99	·764	43 85	67·29
7	61·875	2·664	2·22	137·18	2 07	128·33	1 92	118·80	1·75	108·47	1·57	97·02	1·36	83·58	1·11	68·59	·784	48·51	67·93
8	66·375	2·739	2·27	150·54	2 12	140 81	1·96	130·35	1·79	119·00	1·60	106 43	1·39	92·15	1·13	75·27	·802	53·21	68·50
9	70·875	2·810	2·31	164·00	2·16	153·37	2·00	142·03	1 83	129·63	1·64	115·95	1·42	100·42	1·16	82·00	·818	57·58	69·01
10	75·375	2·873	2·36	177·59	2·20	166 06	2 04	153·79	1·86	140·35	1·67	125·58	1·44	108·76	1 18	88·77	·832	62·79	69·48
11	79·875	2·933	2·39	191·25	2 24	178·84	2·07	165·60	1 8	151·17	1·69	135·23	1·47	117·13	1·20	96·63	·846	67·61	69·90
12	84·375	2·989	2·43	205·03	2·27	191·74	2·10	177·50	1·92	162·05	1·72	144 96	1·49	125 55	1·22	102·52	·859	72·48	70·28
13	88·875	3·040	2·46	218·90	2·30	204·73	2·13	189·54	1·95	173·05	1·74	154·74	1·51	134·02	1·23	109·45	·871	77·37	70·63
14	93·375	3·087	2·49	232·81	2·33	217 77	2·16	201·63	1·97	184·06	1·76	164·59	1 53	142·54	1·25	116·41	·881	82·30	70·95
15	97·875	3·134	2·52	246·78	2 36	230·83	2·18	213·76	1·99	195·11	1·78	174·50	1·54	151·12	1·26	123·39	·891	87·25	71·24
16	102·375	3·176	2 55	260·89	2·38	243 94	2·21	225·94	2·02	206·25	1·80	184·48	1·56	159·75	1·27	130·45	·901	92·24	71·51
17	106·875	3·216	2·57	275·07	2·41	257·20	2·23	238·18	2·04	217·46	1·82	194·50	1·58	168·42	1·29	137·54	·910	97·25	71·76
18	111·375	3·254	2·60	289·31	2·43	270·52	2·25	250·48	2·05	228·68	1·84	204·53	1·59	177·12	1·30	144·65	·918	102·26	71·99
19	115·875	3·289	2·62	303·57	2·45	283 87	2·27	262 81	2·07	239·91	1·85	214·57	1·60	185 84	1 31	151·78	·926	107 29	72·20
20	120·375	3·322	2·64	317 84	2·47	297·25	2·29	275·18	2·09	251·13	1·87	224·62	1 61	194 57	1·32	158·92	·933	112·31	72·41

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5000 feet.																Co-efficient taken.
			2·00		1·75		1·5		1·25		1·00		0·75		0·5		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D.	V	D	
			Depth of water, 5 feet.																
3	52·5	2·496	2·10	110·46	1·97	103·32	1·82	95·66	1·66	87·31	1·46	77·81	1·28	67·36	1·05	55·23	·744	38·90	66·59
4	57·5	2·610	2·18	125·41	2·04	117·30	1·89	108·62	1·72	99·13	1·54	88·32	1·33	76·48	1·09	62·70	·771	44·16	67·51
5	62·5	2·713	2·23	140·63	2·10	131·50	1·95	121·75	1·78	111·13	1·59	99·05	1·37	85·31	1·13	70·31	·795	49·53	68·31
6	67·5	2·808	2·31	156·13	2·16	145·95	2·00	135·07	1·83	123·26	1·63	109·97	1·41	95·24	1·16	78 06	·817	54·98	69·01
7	72·5	2·896	2·37	171·83	2·22	160·59	2·05	148·63	1·87	135·58	1·67	121·08	1·45	104·84	1·19	85·31	·837	60·54	69·64
8	77·5	2·976	2·42	187·71	2·26	175·46	2·10	162·36	1·91	148·18	1·71	132·37	1·48	114·55	1·21	93·85	·856	66·19	70·20
9	82·5	3·051	2·47	203·78	2·31	190·49	2·14	176·30	1·95	160·96	1·74	143·80	1·51	124·41	1·24	101·89	·873	71·90	70·71
10	87·5	3·121	2·51	217·98	2·35	205·71	2·18	190·43	1·99	173 86	1·78	155·31	1·54	134·40	1·26	109·99	·889	77·66	71·17
11	92·5	3·186	2·56	236·34	2·39	221·08	2·21	204·80	2·02	186·85	1·81	166 96	1·56	144·49	1·28	118·17	·904	83·48	71·58
12	97·5	3·246	2·59	252·82	2·43	236·54	2·25	219·18	2·05	199·97	1·83	178·72	1·59	154·64	1·30	126·41	·918	89·36	71·96
13	102·5	3·303	2·63	269·37	2·46	252·05	2·28	223·60	2·08	213·10	1·86	190·55	1·61	164·84	1·32	134·69	·931	95·27	72·30
14	107·5	3·356	2·66	285·95	2·49	267·57	2·31	248·02	2·11	226·21	1·88	202·42	1·63	175·11	1·33	142·98	·943	101·21	72·62
15	112·5	3·405	2·69	302·63	2·52	283·16	2·33	262·46	2·13	239·51	1·91	214·31	1·65	185·40	1·35	151·31	·954	107·16	72·91
16	117·5	3·452	2·72	319·37	2·54	298·80	2·36	276·95	2·15	252·74	1·93	226·20	1·67	195·73	1·36	159·68	·964	113·10	73·18
17	122·5	3·496	2·75	336·33	2·57	314·46	2·38	291·44	2·17	265·98	1·94	238·09	1·68	206·07	1·37	168·16	·973	119·04	73·44
18	127·5	3·538	2·77	353·33	2·59	330·23	2·40	306·00	2·19	279·23	1·96	249·98	1·70	216·41	1·39	176·66	·981	124·99	73·68
19	132·5	3·577	2·80	370·35	2·61	346·09	2·42	320·65	2·21	292·56	1·98	261·87	1·71	226·75	1·40	185·18	·989	130·94	73·90
20	137·5	3·615	2·82	387·48	2·63	362·18	2·44	335·36	2·23	305·94	2·00	273·79	1·72	237·09	1·41	193·74	·996	136·90	74·10

No. CXLI.

THE DURBUNGAH TEMPORARY RAILWAY.

Memorandum on the Construction of a Temporary Railway from the Ganges opposite Barh to Durbungah in February, March, and April, 1874. By Major F. S. Stanton, R.E., *Engineer-in-Chief.*

Service Telegram.

From—Secretary to Government of India, Public Works Department.
To—Major Stanton, R.E., Delhi.

A tramway is required from Chumpta Ghát on left bank of Ganges opposite Barh Station to Durbungah 44 miles long. You are placed in charge: come down sharp with sufficient Engineering staff and plate laying gangs, and bring tools and trollies. Materials for 50 miles will be concentrated at Barh, rails and all fastenings will be sent from Calcutta, except 8 tons of fish-plates and 19 tons fang bolts, which you must supply from Delhi. Furnivall will despatch one lakh sleepers on advice from you; make immediate arrangements for receipt of stores at Barh; telegraph if you want assistance. Arrange for forty ballast wagons to follow you from Delhi. Two Engines expected from England daily. If there is delay arrange so that two may come from Delhi. Make over charge to Furnivall; bring camp equipage and horses ready to take the field.

The above telegram reached me late on the evening of the 10th February at Delhi, and on the 15th April the first train ran into Durbungah, the length of railway made being really 51 miles, exclusive of sidings, instead of 44 as mentioned in the telegram.

The staff belonging to the Delhi District Rajpootana State Railway whom I proposed taking with me to Bengal were warned for the duty on the morning of the 11th February, and arrangements made for the conduct of their duties during their absence; their names were—

Lieut. Rathborne, R.E., Executive Engineer,
Mr. E. J. Moore, Assistant Engineer,
Mr. H. W. Warden, Assistant Engineer,
Shushi Booshun Mookerjee, Supervisor,
Chundee Ram, Plate-layer,
Juggun Nath, Sub Storekeeper,
Shunker Nath, Stores Mohurrir,

to start at once—and Mr. Newton, Plate-layer, with all his gangs, to follow a few days later.

Our horses were sent off on the 13th, and the camp equipage with some necessary tools and plant, trollies, &c., left on the 14th. Arrangements were also made for one locomotive and 20 ballast wagons to be sent down as quickly as they could be loaded.

We left Delhi at 2·45 A.M. of the 17th February, and reached Barh, which is 656 miles from Delhi at 9 A.M. of the 18th; the tents, &c., arriving the same day. Mr. Cochrane, who had been appointed by Government an Executive Engineer for this work, also joined me on the 18th.

The Barh Station of the East Indian Railway is situated about a mile from the bank of the Ganges, but a siding had been laid in to facilitate the transport of grain, and a separate branch from the end of this siding was being laid in for the railway material.

The most important thing at first was of course to arrange for the transport of the railway material across the Ganges, without interfering with the grain transport, so I proceeded to Patna on the 18th, in order to confer with the Commissioner on this point; and it was arranged that all rails, sleepers, &c., should be crossed in country boats, and that a steamer and barge should be given for crossing locomotives, wagons, and any very heavy material.

On the morning of the 19th we crossed the river to Chumpta Ghát, and examined the country as far as Bazetpore, and finding that Chumpta Ghát was 6 miles below Barh, and that there would be great delay in crossing the materials to so distant a point, I determined on starting the railway from some point higher up; and on the 20th, after an inspection

of the river banks, Sultanpore, a ghát nearly opposite the town of Barh, and not more than two miles from the Barh railway siding was decided on.

A few rails had been sent to Barh before the branch siding was complete, but the regular supply of rails and fastenings from Calcutta (300 miles from Barh) and of sleepers from Agra (542 miles from Barh) commenced arriving on the 21st February.

The first rails were boated across the river on the 20th, the first sleepers on 21st, and plate-laying was commenced on the 23rd, but as no fish-bolts arrived before the 3rd March, but little real progress could be made before that date.

The metre gauge railway is peculiarly applicable for temporary railways of this kind, all the parts being light and easily handled; the rails weighed 40 lbs. to the yard, the heaviest only weighed 4 maunds, or 320 lbs.; the sleepers were of deodar, 6 feet long by 8 × 4 inches, and weigh about 50 lbs. each. To have handled heavy broad gauge material, and to have transported broad gauge engines and wagons across a river like the Ganges, would have been a far more serious operation.

On the 21st February I examined the country for about 6 miles north of Bazetpore, and arranged for the crossing of the Balan river near Dulsingh Serai.

On the 26th February I proceeded to Durbungah, with Mr. Stevens, (who had been appointed a Superintendent of Works for the Railway,) to get a general idea of the country through which the railway had to be taken and the rivers that had to be crossed, and returned to Bazetpore on the 27th, having arranged with Mr. Stevens for the commencement of work at the Durbungah end of the line.

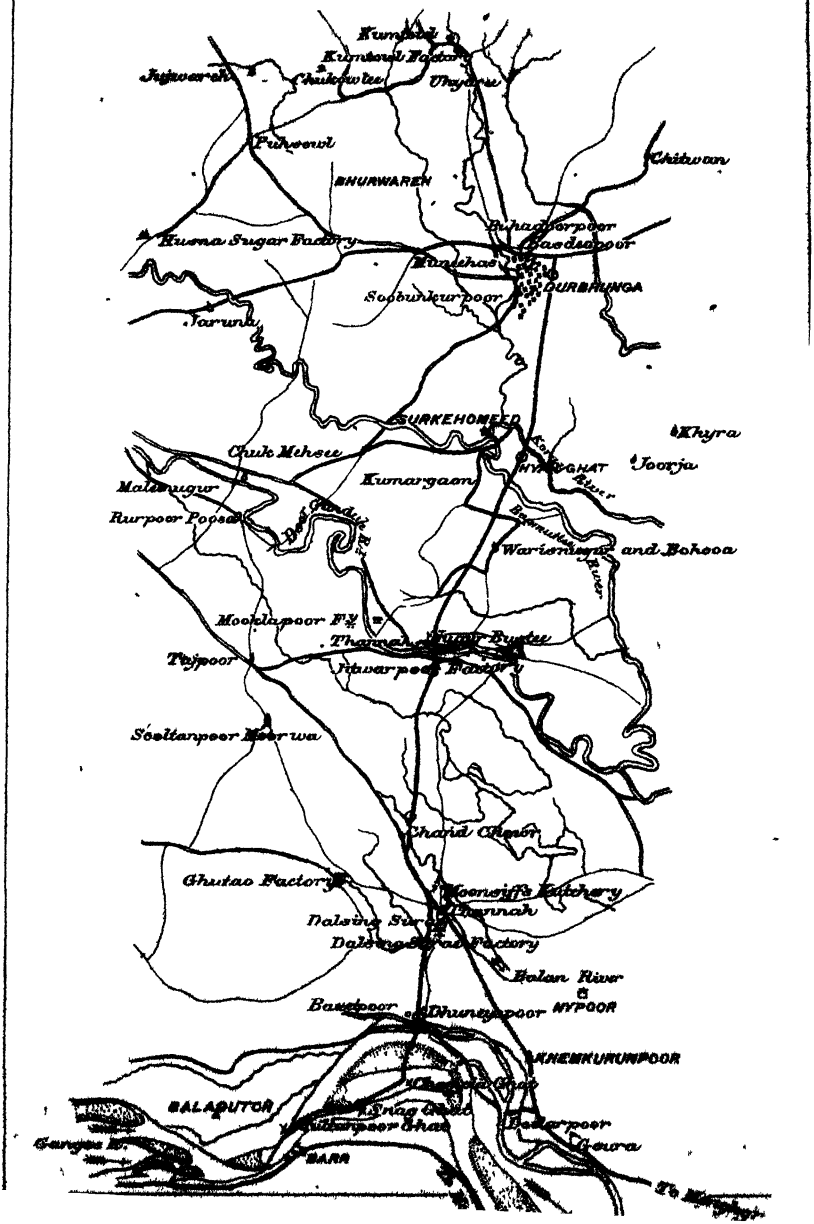
The general features of the line may be described as follows:—

From Sultanpore Ghát to Chumpta Ghát, about 4 miles, the line skirted the bank of the Ganges, thence to Bazetpore it crossed the Ganges khadir, being laid for the most part on the surface of the ground; there were however several depressions or water channels in this portion of the line which required to be crossed on raised embankments: the principal of these was the channel of the Byah, in which there was about 5 feet of water when the line was made, but as there was no current, an embankment only was required. Just beyond this channel the high permanent bank of the Ganges is reached at Bazetpore.

From Bazetpore the line is laid generally on the surface of the ground

DURBUNGAH (TEMPORARY) RAILWAY.

Scale, 8 British Miles = 1 inch.



to the 13th mile, where the Balan river is crossed; there was about 6 feet of water in this but no perceptible current, so an embankment was here also resorted to, with a small opening left to prevent any heading up: the banks of this river being high, it was necessary in order to save time and heavy earthwork to cut through them, and approach the embankment across the river itself by steep inclines of 1 in 60 on each side.

From the 13th mile to the Boor-Gunduk river at the 29th, the line is also for the most part laid on the surface of the ground, all hollows and dry channels being filled up.

The Boor-Gunduk is a considerable stream, the width of water in the dry season being over 200 feet, and the depth varying from 5 to 8 feet. Here a pile bridge was necessary, and 105 feet of waterway was given, the river being embanked at both ends of the bridge.

From the Boor-Gunduk, the line was taken partly along a raised road and partly on a newly formed embankment to the Bagmuttee river at the 40th mile, where another pile bridge, consisting of four spans of 15 feet was required.

From the Bagmuttee to the Koraye river at the 42nd mile, (where another bridge also of 4 spans of 15 feet was required,) the road is also utilized for a part of the way, and from the Koraye River to Durbungah, a new embankment was thrown up, but not being quite ready by the time the plate laying reached this part of the line, the rails were laid on the surface of the ground to within about 1 mile of Durbungah; from this point they were laid on the embankment to the commencement of the Durbungah station yard, 51 miles from Sultanpore.

On arrival at Barh, I applied for the services of two companies of Sappers; the application was granted, and they arrived at Barh from Roŏrkee (770 miles) on the 27th and 28th February. The 32nd Pioneers were also placed at my disposal; they arrived at Barh from Umballa on the 7th March.

The engine from Delhi arrived at Barh on the 24th February, but arrangements for unloading and transporting it across the Ganges could not be completed before the 28th, by which time a jetty had been built of sleepers and sand bags, and rails laid down an incline to the jetty—the engine was placed on the barge on the 1st March, and with 5 ballast wagons, was taken across the river to Sultanpore on the 2nd. Here a similar jetty had been prepared for unloading engines and wagons, and

the first locomotive was safely landed on the north bank of the river on the 3rd of March. Steam was first got up on the 5th, and a train load of materials ran to rail head 5 miles from Sultanpore.

From this date the work commenced in real earnest, as until a train was ready to carry forward materials from the ghát to rail head, the progress could be but nominal, owing to want of carriage.

Cart carriage was a difficulty from the commencement, as nearly all the available carriage of the country was employed in the transport of rice; but the Magistrate of Tajpore, Mr. Wace, arranged for 100 carts to come to me from his Sub-Division, and a little later a number of the Government reserve carts were placed at my disposal by Col. Mackenzie and Col. McGregor.

As soon as carts were available, the necessary plant and material for the bridge over the Boor-Gunduk at Nagur Bustee was sent forward; the piles for the bridges sent from Calcutta, and the pile engines bought from the Oudh and Rohilkund Railway Company, having in the mean time reached Barh.

The system adopted for carrying on the work was as follows:—The line was first ranged out, and the curves put in by the Engineers in charge, when a gang of men, under an Overseer, were sent forward to clear trees and to level and dig up the surface of the ground, in order to give the sleepers an even bearing. On the arrival of the Sappers and Pioneers, this duty was entrusted first to Lieut. Morgan, R.E., with the 5th Company, and subsequently to half the Pioneers, under Col. Williams, until both these parties were detailed for the bridge construction.

The head quarters of the Pioneers, and the 6th Company of Sappers, under Lieut. Dove, were kept near rail head to unload material trains on arrival, and assist in the plate-laying, until it became necessary to send this Company of Sappers to Barh, to assist in the unloading and transport across the river of the working rolling stock.

As soon as the road was ready for the sleepers, a gang of men distributed them along the line, followed by another gang who ranged them in proper line, and duly spaced them.

On the arrival of a train with materials at rail head, the Sappers and Pioneers were told off 8 to each pair of wagons to unload the rails, sleepers, &c.; the unloading of a train taking from half to three quarters of an hour.

The sleepers were then carried forward either by coolies or on carts and placed as noted in the preceding paragraph; and the rails were similarly dealt with, being deposited in pairs alongside the sleepers; the fastenings were placed on trollies, and moved forward as the rails were laid, a small quantity being regularly distributed ahead by boys especially told off for that service.

The plate-laying was of course the most important part of the work. The rails used were flat footed, weighing 40lbs. to the yard. They were jointed with fish-plates and bolts, and spiked to cross sleepers The rails are mostly 24 feet long, requiring 9 sleepers to each pair of rails, the sleepers being spaced, and the rails laid alongside, the plate-laying gang commenced their work, a certain number (four to a rail) lifted the rails on to the sleepers, placing them butting one on another on each side. A gang of men then followed distributing fish-plates and bolts at each joint, when the men told off for the purpose immediately attached the fish-plates at the rail joints, fastening them however with only two bolts instead of four. These men were closely followed by the auger and spike men who with their rail gauges applied, spiked down the rails to the sleepers at the joints, and at alternate sleepers only between joints, thus spiking five out of the nine sleepers to a rail.

Following these men came a party with levers to straighten the line; after which operation some coolies filled earth between the sleepers and partially packed them.

This first large gang of plate-layers, was then followed by an entirely separate gang, who completed the joints and spiking, and properly packed the road.

As soon as the plant and material for the temporary bridge over the Boor-Gunduk reached its destination, Lieut. Morgan, R.E., and the 5th Company of Sappers, and the detachment of Pioneers under Col. Williams, were moved forward to that river to construct the bridge. The direction of the work was placed in the hands of Lieut. Kunhardt, R.E., Assistant Engineer. The first pile was driven on the 21st March, and the bridge consisting of 7 spans of 15 feet, was completed by the 28th, on which day the first train passed over it; the Sappers and Pioneers having worked in reliefs night and day, in order to get it completed by the time the plate-laying reached the river.

On the completion of the Boor-Gunduk bridge, Lieut. Morgan with

his Sappers was moved on to the Bagmuttee river, the construction of the bridge over which was entrusted to him, while Lieut. Kunhardt with the Pioneers under Col. Williams were sent to the Koraye river. The bridges over both these rivers consisted of 4 spans of 15 feet. The first train passed over the Bagmuttee bridge on 4th April, and over the Koraye on the 7th April.

After the completion of the Bagmuttee bridge, the Sappers under Lieut. Morgan, were employed in assisting in the plate-laying, and I believe the men learnt a good deal of this duty from Mr. Newton the plate-layer.

There was some very heavy earthwork in cutting in the inclines made, 1 in 100, to both these bridges, more particularly at the Koraye, but by great exertion on the part of the Engineers in charge, the plate-laying was scarcely delayed at all.

After passing the Koraye, there were no further difficulties to be encountered, and the plate-laying went steadily on, the first train reaching the Durbungah station yard on the 15th April.

His Honor, the Lieutenant-Governor of Bengal, opened the line on the 17th April, on which day the first grain trains ran to Durbungah. The carriage of grain to Nagar Bustee had commenced on the 3rd April, but owing to the paucity of engine power available at that date, no great quantity could be carried until later.

The Ganges river intervening between the railway and its base of operations at Barh, was the only serious obstacle to the rapid construction of the work; more than 6,000 tons of permanent way material, besides 10 locomotives and 233 vehicles had to be transported across the river, and in addition about 1,000 tons of iron bridge material, brought from Bombay with the intention of replacing the temporary bridges by permanent structures, were carried across.

The plate-laying could have been carried on rather faster, had there been more engines and wagons available at first to lead forward materials; as when the rail head was more than 20 miles from the river, it became impossible for the one engine and 20 wagons to keep up a full supply of material; the maximum length of plate-laying done in any one day was two miles, the average (excluding the work up to the 5th March) being over one mile daily; the last 46 miles, exclusive of sidings, being completed in 41 days.

I exclude the work up to the 5th March, as it was not until that day

that we had any means of leading forward material, and it was only on the 3rd that the first supply of fish-bolts was received.

While the line was in progress, temporary houses for the staff were erected at Bazetpore and other stations, the houses consisted of sál tree posts, supporting a tiled roof with wattle and daub walls.

Exclusive of the labour employed on the heavy earthwork in the cuttings at the river approaches, and on the new embankments, intended for the more permanent line, the average number of men employed daily inclusive of Sappers and Pioneers, was about 1000.

The rolling stock was supplied from various sources: 2 engines were sent from Delhi, 1 from Agra, and 7 from Calcutta; of the new ones, two were erected at Barh, one at Bazetpore, and the others at the East Indian Railway shops at Jamalpore.

The wagons were sent from Bombay, Khundwa, Calcutta, Agra and Delhi, and it was not until some time after the line was completed to Durbungah that the whole of the stock—10 engines and 233 vehicles—had been placed on the line, and to the last the grain transport was interfered with by the necessity of leading forward the iron bridge material, and a large quantity of coal for burning bricks and ballast for the intended more permanent line.

As mentioned above, the first grain was carried to Nagar Bustee on the 3rd April, and to Durbungah on the 17th. The total quantity of food grain and cattle fodder carried between those dates and the end of May when I left Tirhoot to return to Delhi was as follow:—

To Durbungah,	...	...	...	...	Maunds,	3,79,898
„ Hya Ghát,	...	...	...	...	„	94,226
„ Nagur Bustee,	...	...	...	...	„	3,07,583
„ Dulsing Serai,	...	...	...	...	„	93,258
			Total,	...	„	8,74,965

the total maund milesage being 3,17,96,911.

The contract rate paid by Government for the carriage of grain was 3 pie per maund per mile, and it is fair to credit the railway for the work done at this rate. A quantity of grain was carried after I left; but the amount for this quantity, Rs. 4,96,827, would more than cover the entire cost of laying and working the temporary railway, and of removing it afterwards, had such been the wish of the Government, but exclusive of all charges due on account of the more permanent line which it was the wish of Government to have constructed, and which should be considered

quite apart from the cost of constructing and working the temporary line for the emergency which called for its construction.

The Officers of the Engineer Establishment employed on the construction of this line were as follows:—

Mr. H. M. Stevens, Superintendent of Works.
Mr. J. H. Cochrane, Executive Engineer, specially appointed for Tirhoot Railway.

Lieutenant Rathborne, R.E., } From Delhi District Rajpootana State Railway.
Mr. E. T. Moore, }
Mr. H. W. Warden, }

Lieutenant Kunhardt, R.E., } From Punjab Northern State Railway.
Mr. W. Foster, }
Mr. A. S. Gerrard, }
Mr. J. Robertson, }
Mr. G. Humfress, }

Mr. Burt, } From Special Famine Relief Works.
Lieutenant White, R.E., }

F. S. S.

No. CXLII.

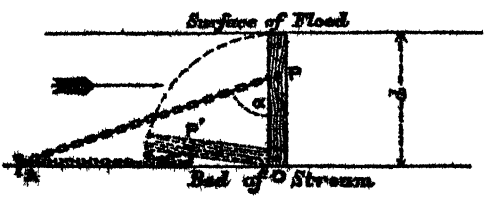
ON THE TENSION OF CHAINS OF A SLUICE-SHUTTER.

By Capt. Allan Cunningham, R.E., *Hony. Fell. of King's Coll. London.*

The following is an investigation of the amount of Sudden Tension of the retaining Chains of a Sluice-Shutter.

[The Problem was proposed to the author in connexion with the Sluices of the Midnapore Weir, the chains of the shutters of which have frequently failed unexpectedly, *i.e.*, under strain hitherto supposed to be much below their proof strain].

The action of the shutter is as follows:—"The shutter lies ordinarily at the bed of the stream (as OP') *with its head* (P') *towards the current*, and is—when the current attains a sufficient velocity—rapidly raised by the current itself, rising on hinges (O) at the bed of the stream, and *is suddenly checked* by the retaining chains (AP) when it has attained a nearly vertical position, (as OP)."



It is further supposed that the shutter is rectangular, and that the retaining chains are applied at points on a horizontal line through the "centre of percussion" (P) of the rotating shutter, and also that the depth of the stream is the same as the height of the shutter.

The Problem proposed is to find the Tensions of the chains at the instant they are strained suddenly taut.

A proper solution of the Problem appears (to the author) impossible, owing to the imperfect state of Hydraulic Science. The following is only proposed as an imperfect attempt towards it, and the final Result (13) can only be looked on as a rough approximation.

The Problem is greatly complicated by the gradual conversion of the IMPACT proper of the water into simple PRESSURE as the shutter rises, and by the conversion of the momentum of the fluid into angular momentum of the shutter.

But it seems to the author that—inasmuch as the chains are scarcely strained at all (except by their own weight) until the shutter has come to its final (vertical) position, and as whatever momentum may be impressed on the shutter must have been parted with by the water—it will be sufficient to consider the *whole momentum of the current at its full depth* as being suddenly stopped by the shutter when in an upright position, and thus suddenly applied to the Chains.

The following notation will be used:—

Let b = breadth of shutter *in feet.*

d = depth of shutter = depth of stream } *in feet.*

V = Mid-surface velocity (over shutter when down) *in feet per second.*

w = weight of a cubic foot of water = 62·5 lbs.

g = measure of acceleration of gravity = 32·2.

P = Total Impulse of fluid on area bd *in lbs.*

T = Total Sudden Tension of the whole set of Chains *in lbs.*

α = Inclination of chains to shutter *when vertical, i.e.,* at instant when strained taut.

Other notation is explained in the text.

Consider the circumstances of motion of a *slender* (longitudinal) filament of the fluid of sectional area (a) moving with a velocity (v).

The pressure (p'') due to the *continued impulse* of such a filament upon a *small* plane area (a) perpendicularly opposed to it is given in Art. 648 of Rankine's Applied Mechanics, Eq. (4) and (5),—

$p'' = w\,a\,\frac{v^2}{g}$, if the fluid be *free to escape on all sides* at right angles to its original motion, } ... (12).

$p'' = 2\,w\,a\,\frac{v^2}{g}$, if the fluid be turned back in the reverse direction of its original motion, } ... (13).

The roof of the watch tower is boarded, supported on deodar wood rafters. The opening of the wards are filled with gratings of iron bars, $1\frac{1}{2}'' \times 1\frac{1}{2}''$, placed 4 inches from centre to centre, and stiffened with horizontal flat bars of iron $3'' \times \frac{1}{2}''$.

These gratings are fitted on the inside of the door frames, the outside being provided with battened shutters of deodar wood.

The doors of the cells consist of keekur wood, covered with sheet iron, having openings $12'' \times 12''$, (fitted with 1 inch iron bars,) both at top and bottom, for purposes of light and ventilation. In addition to this ventilation, each cell has an iron barred window $1\frac{1}{2}' \times 1\frac{1}{2}'$ above the door, with a large ridge ventilator $6' \times 9''$, which is considered ample.

The doors of hospitals are half pannelled and half glazed, and those of the European ward are also the same, but provided with iron gratings inside. The windows of the European ward are iron barred, fitted with glazed frames outside, for purposes of light. In addition to this, there is a roof ventilator $12'' \times 12''$ in each room of the ward.

A covered passage from the European Ward leads to the privy close to it.

The doors of the offices, godowns, and darogah's quarters, are panelled, and of the rest of the buildings common battened, all of deodar wood.

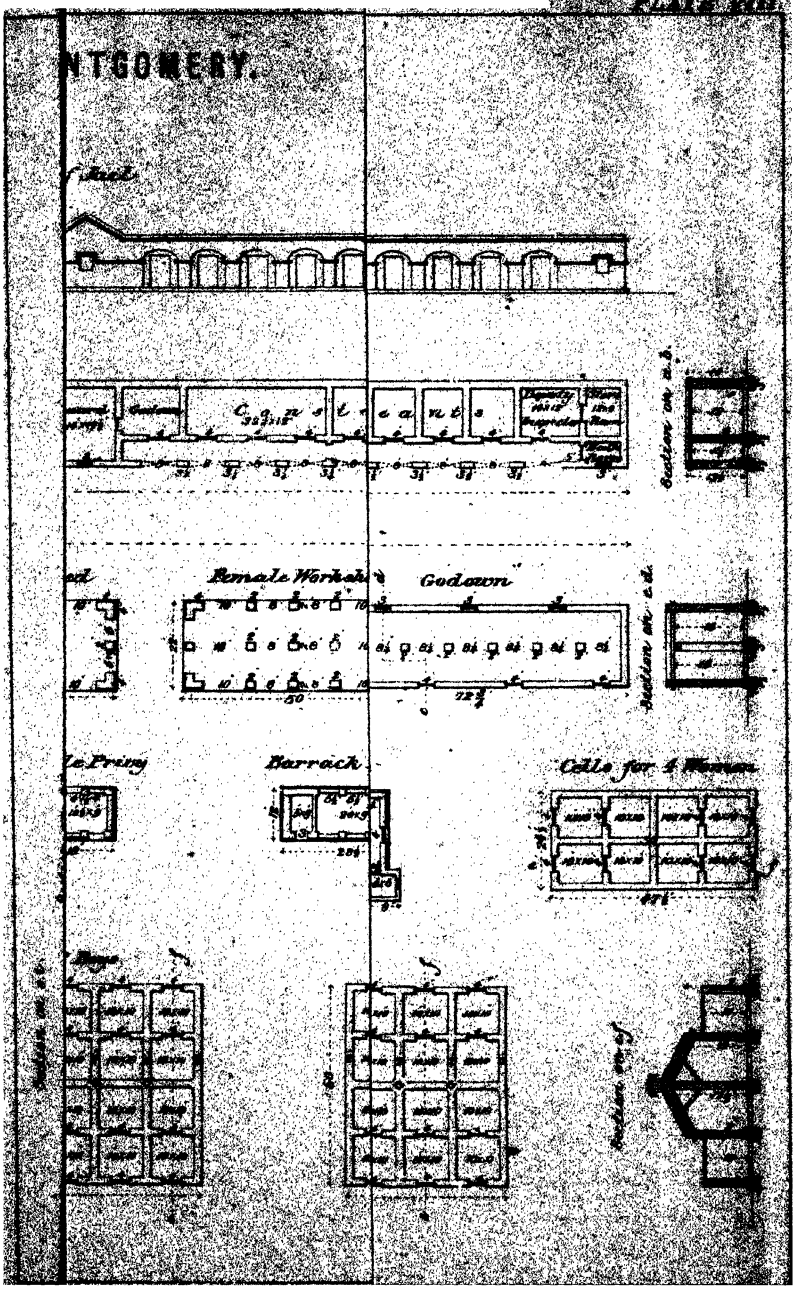
The gates are of iron bars $1\frac{1}{2}'' \times 1\frac{1}{2}''$, fitted into a rectangular frame of flat bars, and stiffened with diagonal and flat bars of iron $3'' \times \frac{1}{2}''$.

A narrow passage from the inner circular enclosure, leads to the gates towards the workshop, which are made so, that when they are closed at night, a communication is opened at the back from one side to the other, and the sentry can thus go round the jail; and when they are opened during the day, a communication is formed between the jail and the workshop, while the communication at the back from one side to the other is closed.

A space of about 10 or 12 feet round all the buildings is metalled with broken bricks, with a slope outwards, so as to lead the drainage away from the buildings. Shallow kucha drains discharge the water from the inner circular enclosures, and also from the different compartments into a large circular drain outside the outer circular enclosure, which discharges its contents into the main drainage channel outside the jail.

There are eight wells in the jail area, with one well outside the gate, and four in the garden enclosure. The wells in the jail have a cylinder 5 feet inner diameter, of burnt bricks laid in lime mortar up to about 3 feet above the water's edge, and the rest is made of burnt bricks laid in mud

NTGOMERY.



mortar, the whole pucka plastered inside. The wells in the garden are 10 feet inner diameter, and fitted with Persian wheels for purposes of irrigation.

The wells in the jail compartments and the hospital are provided with reservoirs and platforms for bathing purposes, the former being so high, that all waste water runs into the grass plots in the compartments, instead of being collected in cisterns or cesspools, and emptied once or twice a day as is the case in other jails.

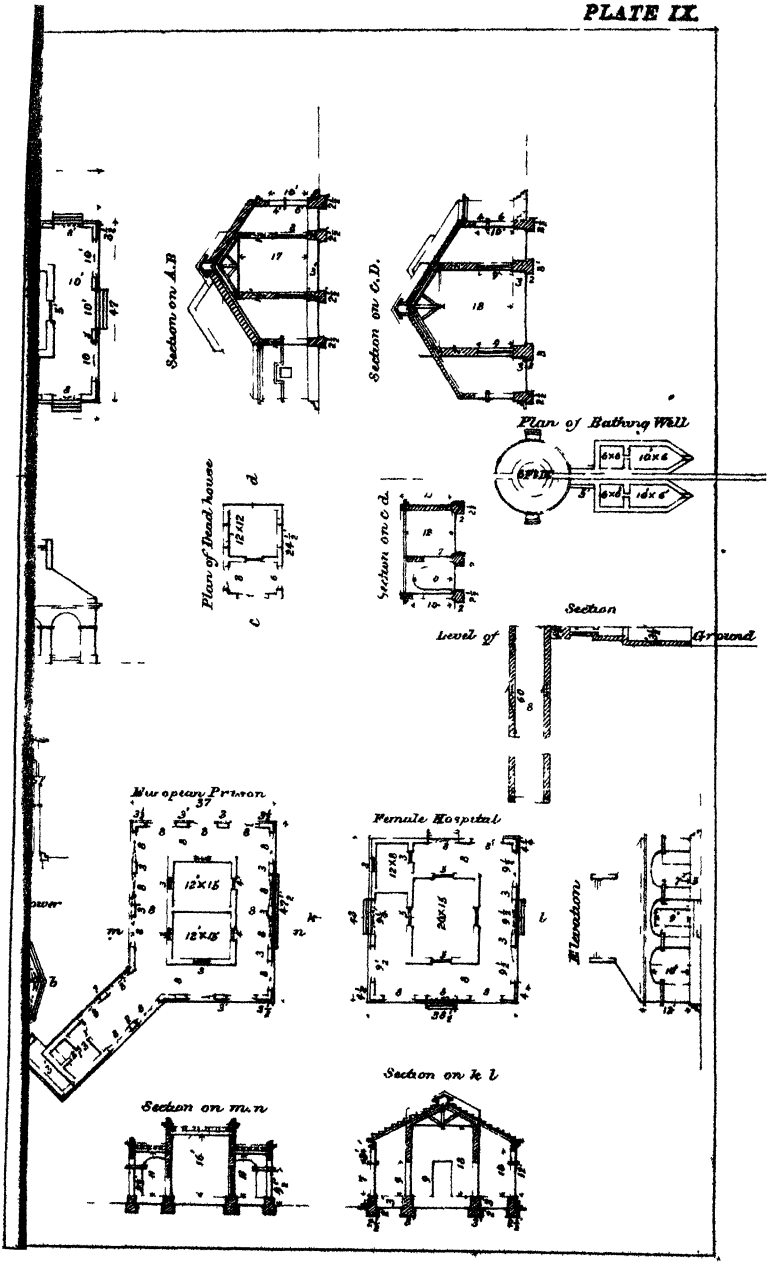
This jail is intended to accommodate 540 prisoners, (500 in the wards and solitary cells, and 40 in quarantine cells,) and has cost Rs. 1,62,230, or Rs. 300 per prisoner.

The following Abstract shows the details of cost, giving the quantities of work executed in the Jail, together with the actual working rates, &c.

		Rs.	A.	P.
c. ft.				
3,06,916	Kucha masonry, at Rs. 2 per 100, ...	6,083	7	11
2,09,250	Kucha pucka masonry, at Rs. 7 per 100, ...	14,434	2	2
2,37,255	„ „ „ pucka pointed on the outside, at Rs. 8 per 100, ...	15,161	12	9
85,337	Pucka masonry, at Rs. 14 per 100, ...	11,011	14	8
19,289	„ „ Rs. 16 per 100, ...	2,931	5	8
1,124	„ „ Rs. 18 per 100, ...	202	0	0
s. ft.				
85,874	Pucka plaster of coping, at Rs. 4 per 100, ...	3,433	1	6
65,604	Kucha flooring, at Rs. 0-4-0 per 100, ...	132	4	2
c. ft.				
1,84,114	Filling in earth, at Rs. 0-4-0 per 100, ...	402	4	10
s. ft.				
9,913	Battened doors, at Rs. 0-10-0 per foot, ...	6,183	14	8
2,019	Battened, panelled, and glazed doors, at Rs. 1 per foot,	2,033	5	1
16,268	Battened iron grated doors, at Rs. 1-14 per foot, ..	30,501	10	0
3,440·66	Battened sheet iron, at Rs. 1-8 per foot, ...	5,159	8	11
r. ft.				
5,861	Pucka drip cornice, at Rs. 20 per foot, ...	1,006	5	7
s. ft.				
25,894·36	Goodwyn tiled roofing, at Rs. 35 per 100 feet, ..	8,471	15	1
1,350	„ „ Rs. 40 per 100 feet, ..	528	8	3
39,575·42	„ „ Rs. 50 per 100 feet, ..	18,904	11	5
7,521	„ „ Rs. 60 per 100 feet, ..	3,036	4	4
38,768	Flat bullee roof, at Rs. 14 per 100 feet, ...	5,178	10	7
2,752	Flat roof on beams and kurrees, at Rs. 30 per 100 feet,	815	3	2
	Carried forward, ..	135,712	6	9

		Rs.	A.	P.
	Brought forward, ..	135,712	6	9
s. ft.				
2,363	Boarded roofing, at Rs. 35 per 100 feet, ...	826	11	1
60	Perforated zinc sheets, at Rs. 1 each, ...	60	0	0
c. ft.				
1,706	Wooden architraves, at Rs. 1-8 per foot, ...	2,490	4	5
2,112	Pucka plaster inner, at Rs. 3 per 100, ...	62	1	1
80,991	Pucka whitewashing, at Rs. 0-2-0 per 100, ...	99	2	2
5,205	Brick flooring, at Rs. 8 per 100,..	281	2	8
13,981	Tile flooring, at Rs. 10 per 100,..	418	5	3
	Fitting up shelves in hospital, ...	119	12	6
r. ft.				
329	Pucka cornice, at Rs. 12 per 100, ...	39	0	0
mds.				
5	Wrought-iron, at Rs. 22 per maund, ...	110	0	0
No.				
2	Entrance gates of iron, at Rs. 300 each, ...	500	0	0
2	Barrier gates of iron, at Rs. 350 each, ...	662	0	0
7	Drinking wells, at Rs. 500 each, ...	2,028	14	11
6	Bathing wells, at Rs. 750 each, ...	3,511	6	7
s. ft.				
113,483·59	Kucha masonry, kucha plastered on both sides, at Rs. 2-8-0 per 100, ...	840	7	0
17,800	Pucka plaster of coping, at Rs. 3-8-0 per 100, ...	610	12	11
No.				
2	Entrance gates of wood 10′ × 14′ each, complete, at Rs. 69, ...	138	0	0
c. ft.				
70,359	Kucha masonry in foundation, plinth and superstructure of quarantine cells, at Rs. 3 per 100, ...	942	6	1
9,466	Kucha masonry in foundation, plinth and superstructure of round doors of quarantine cells, at Rs. 3 per 100, ...	92	14	0
20,512	Kucha masonry of cross walls of inner sleeping chubootras, at Rs. 3 per 100, ...	168	13	9
s. ft.				
4,000	Flat roof on bullees, at Rs. 16 per 100,..	419	8	10
c. ft.				
5,632	Kucka pucka masonry of coping of walls and of waterdrips, at Rs. 5-8-0 per 100, ...	81	14	11
No.				
1	Well outside quarantine cells, at Rs. 500, ...	496	10	0
	Compound wall and gate of quarantine cells, ...	168	15	6
	Part jail labor, ...	7,501	13	9
	Contingencies, at Rs. 5 per cent., ..	8,950	4	11
	Grand Total, Rs., ..	1,62,228	13	1

K. L.


Section on A.B
Section on C.D.
Plan of Bathing Well
Plan of Dead house
Section on e.d.
Section
Level of
Ground
European Prison
Female Hospital
Elevation
Section on m.n
Section on k.l

'Gutta gambier' is juice extracted from the leaves of a plant of the same name, *Uncaria Gambier*, growing in Sumatra, inspissated by decoction, strained, suffered to cool and harden, and then cut into cakes of different sizes, or formed into balls. Chief places of manufacture, Siak, Malacca and Bintang. It is used by the Malays with the leaves of betel in the same manner as cutch *(catechu)* in other parts of India. For this purpose the finest and whitest is selected, the red being stronger tasted and rank. Is exported to Batavia and China for purposes of tanning and dyeing."

Captain Fraser's process.—In 1856 the magazine flooring and powder-racks in Fort William, Calcutta, had to be renewed in consequence of the injuries caused by white-ants.

Captain Fraser, R.E, removed the whole of the old floor, stripped the plaster from the walls, for a height of 4 feet, and dug out the earth to a depth of 1 foot.

The excavation was filled up with concrete; masonry pillars were built for the support of the joists, which were painted and overlaid with 3-inch planks, and the walls were re-plastered.

The concrete, the mortar in the masonry pillars, the sand plaster, and the paint, all contained a proportion of the yellow arsenic known in the bazaar as *hurtal*, the proportions used being as follows:—

100 cubic feet concrete,	.. ..	4 lbs. arsenic.
100 „ masonry,	.. ..	½ lb. „
100 s. feet plastering,	.. ..	¼ „ „
Paint, a small quantity.		

This plan was perfectly successful. Captain Fraser writes—

"In 1856 not only the building, but the whole immediate neighbourhood, was swarming with white-ants." In 1859, or three years afterwards, the Town Major reported that, "the flooring and powder-racks in the King's Magazine have been carefully examined, and no traces of white-ants have been found either inside, or outside the building."

On the 16th March, 1874, the Executive Engineer, Fort William, in reply to an enquiry on the subject reported as follows:—

"Since 1859 no repairs have been executed to the floor racks of the King's Magazine; no traces of white-ants are to be found, and the floors and racks are in fair condition."

So the process appears to have met with complete success.

Bombay P. W. D. recipes.

(a). Bombay Chief Engineer's recipe 1858.—

A mixture of sulphate of copper, or of arsenic, with the lime in immediate contact with timber, offers, perhaps, the most ready method of preserving it from insects; corrosive sublimate combines with lime, and forms an inert substance ('yellow wash' of medicine).

(b). Madras recipe.—

	lbs.	oz.
Arsenic, ...	2	4
Aloes, ...	2	4
Chunam soap (common country), ...	2	13
Dhobie's mud (khar), ...	2	8

Pound the arsenic and aloes, scrape the soap, mix with the mud, and boil in a large chatty half-full of water until it bubbles; let it cool, and when cold, fill up with cold water; the mixture should be boiled for an hour. It is applied as a wash.

(c). Dr. Hewlett's recipe.—

Take 1 lb. of McDougall's sheep-dipping composition (ointment), and mix with 5 gallons of water.

To destroy white-ants, pour this solution over places infested by them.

To preserve wood, soak it in the solution, or smear it with the ointment.

It appears evident from the foregoing description of the process, that however successful it might be as a means of destroying the insects, it was not likely to be a lasting preservative from their attacks.

The experiments made in Bombay in 1866, though successful as far as they go, are very inconclusive as regards the real merits of the process, and the further experiments made in Bombay in 1870, show that it was by no means a perfect preservative.

The conclusions of the Bombay Government are thus summed up—

"1*st*.—That McDougall's sheep dipping composition is not a perfect preventive against the ravages of white-ants.

2*nd*.—That the composition checks the destructive inroads of these insects only for a time, varying according to the description of the timber.

3*rd*.—That well-seasoned blackwood, teak, and funsee (jack-wood) resist the attacks of white-ants."

Cullen's Process.—Cullen's composition is composed of the following ingredients:—Lime, coal-tar and moulder's blacking: and the cost is stated to be 28 shillings per 100 gallons.

The composition is a patent; the exact proportions of the ingredients and the mode in which they are mixed is given in the patent specification. The preparation is a fluid one.

The patentee claims for it that, when applied to *wood*, it renders it secure against the attacks of white-ants, and that when applied to *iron*, it protects it against rapid oxidization, specially in damp situations.

To apply it to *wood*, the fluid should be heated to boiling point, and the timber immersed in it for one hour, care being taken to maintain the boiling. For *iron* it should be heated and put on with a stiff brush.

The inventor states that 6 pieces of wood, of which 3 were coated with his preparation, were buried in a place much infested with white-ants; after a period of five months they were taken up, the coated pieces were "perfectly sound and untouched, but the uncoated pieces were eaten away one-third their original size."

Iron similarly buried in a damp place showed the coated pieces to be in a "perfect state of preservation; the uncoated were very rusty."

Wood sent out by Mr. Cullen prepared with his composition was buried at Bhaugulpore with like results, but the Executive Engineer reported a tendency in the composition to "peel off."

Subsequent experiments were carried out on a small scale, and with much the same result.

Apparently, the preparation is likely to act as a preservative for only a limited time.

One of the reports states that coal-tar used by itself was found to be just as effective as the composition.

Processes for Railway Sleepers.—From papers recorded in the Office of experiments carried out in Norway and Germany, the following results have been deduced:—

1st.—That impregnating with creosote and chloride of mercury (kyanizing) at a great pressure has been most successful, but the operations were most costly of any.

2nd.—That chloride of zinc has been proved to be most useful when great pressure was applied.

3rd.—That sulphate of copper was found to be less to be depended

on: but this may arise more from the way it was employed, rather than from the substance itself.

4th.—It is certain the results have been very unfavourable without pressure, and when the wood has been cold steeped.

5th.—That impregnating with sulphate of iron and sulphate of barium is useless, and has been discontinued everywhere.

It is also stated that some of these processes appeared, when tried in this country, to have the effect of weakening the strength and durability of the timber, and inducing in some cases a species of dry-rot; and that they did not prevent the wood from being attacked by beetle-borers.

Experiments were also tried at the Calcutta Mint by immersing sleepers in coal-tar, but though the sleepers were left immersed for 60 days, there was scarcely any penetration of the tar into the wood, and the experiments were ordered to be discontinued.

Creosoted pine sleepers have been buried for two years in the Government Telegraph Store-yard at Alipore, a place which is infested with white-ants, and are found to be perfectly sound with one exception, and that one has been destroyed by dry-rot; there is no sign of damage by white-ants.

Bangalore D. P. W. recipe.—The following specification is given in the estimate for the Museum at Bangalore.

"A thin layer of the following composition to be laid over all walls at basement level, and again 1 foot below their tops to keep off white-ants from the floors and roofs.

8 bottles of coal-tar.
1 bottle of linseed oil.
3 drams of kerosine.
2 lbs. of asphalte.

It is not known whether this preparation has been practically tried.

Forbes' priming.—The principle of this process, which is a patent, is, to use the inventor's own words, "the combination of sulphate of copper in certain proportions with any vegetable oil, but I find linseed oil to be the best."

The sulphate of copper is finely ground, and then intimately mixed with the linseed oil, the proper proportions are given in the patent specification. The mixture, when prepared, is rubbed over every part of the timber to be protected; when thoroughly dried, two coats of priming are

laid on with a brush; the ingredients of the priming are white-lead, chalk and sulphate of copper, and linseed oil, and the proportions are given in the patent specifications.

The experiments made by the inventor for six months show success but the period is too short to be a conclusive one. The Bengal Government in a recent letter puts up papers showing the results of further experiments, and it is characterized by Colonel Nicolls as having been "tried with partial success."

Experiments have been made with Forbes' priming on a tolerably large scale on the telegraph posts in the Punjab and elsewhere. The results are reported to have been "conflicting."

Burmah D. P. W. recipe.—Mr. Bennett, Exec. Engineer reports that, "in British Burmah, Port Blair, where the majority of buildings were wooden structures, the whole of the timber is coated with earth-oil, which is laid on warm before the timber is put into the building, yearly coatings being also laid on prior to the rains. The effect of this is very surprising. The cost is 8 to 12 annas per square of 100 feet."

Rohilkhund D. P. W. recipe.—The practice which obtains in Rohilkhund, is to "char the ends of all rafters slightly, and then coat them over with coal-tar, which costs from 3 to 4 annas per cubic foot.

N. W. P. Forest Dept. recipe.—The Conservator of Forests, North Western Provinces, says—"Sulphate of copper mixed with the mortar just above ground level contiguous to wood framing of doors, windows" &c., and just under level of roof timbers, is the best precaution known to me. An old Forester (the late Mr. Finn) told me that he had never known the following fail with a pucka house:—"Scrape the ground surface all over foundations, and to a width of 20 feet beyond it. This will expose the minutest white-ant burrow, which must be traced down until the queen ant is discovered and killed. Mr. Finn assured me that white-ants never burrowed down from outside and up inside a house, and that he had known houses in which this precaution had been taken stand out free from the ravages of white-ants, whilst all neighbouring houses were infested with them."

He adds that he had "tried a solution of sulphate of copper on an extensive scale, but with no great success."

18th June, 1874.

No. CXLV.

NOTES ON NORTH BHAUGULPORE—BENGAL.

[Vide *Plates* XI. and XII.]

By E. A. Sibold, Esq., *Exec. Engineer, (late) North Bhaugulpore Division.*

The greater and more valuable portion of the Bhaugulpore District lies north of the Ganges. During four months of the year, it is almost entirely cut off from the south by the inundations of the Ganges and its tributaries; from the north by the jealous exclusiveness of the Nepál Government, and from the east by the treacherous and shifting Kosi. It is peopled by a race whose virtues and affections have been crushed out by a selfish apathy. The heat being pleasant, but enervating all the year round, the luxury of a warm sun tempered by a tropical shade is one that even the poorest can indulge in; beyond this, little more is required than barely enough to support life, and this the natives' idea of happiness, makes them careless of anything, but a dreamy enjoyment of the present. Nor does the manner of life of those who are wealthy differ essentially from that of the poorest. The former eat finer rice, and possess more huts, but in other respects, the outward appearances are alike. To such dreamers, famine is little more than a physical pain unaccompanied by the sentimental horrors with which it is invested by more energetic races. Even in the most prosperous and seasonable years, a large portion of the population exists in a precarious manner, as the returns of agriculture as practised at present, are not sufficiently large to feed all properly, and there are no manufactures, and no trade to relieve the pressure of

population. Possibly better means of communication, by bringing in new ideas, may induce a more active struggle for, and a keener enjoyment of, the comforts of civilization. In this country, the most elementary Engineering works are wanting. The people are strictly conservative in their ideas, in fact, absolutely hostile to attempts at improvements, having little trade to open out connections with others, and content to live in extreme poverty. Excepting at Pertabgunge and Khagaria, there are none of the substantial buildings and large bazars so common in Northern India. Clusters of villages do hold market days fortnightly, or at most weekly for the purchase of household necessaries, but here everything is bartered for, and money is not current to any extent. The people are all clothed with Manchester goods, Colgong being a great mart for piece goods and country produce, but as they rarely indulge in a new piece of cloth, the consumption is limited. Colored cloths are not in much demand. The first class marts are—

1. *Pertabgunge.*—Chiefly imports for the Nepálese.
2. *Bulloa.*—Grain exports to Calcutta and other places.
3. *Khagaria.*—A great place of call for all the boat traffic above Calcutta.
4. *Murligunge.*—Five miles north of Kisshangunge.

The second class marts are Peepra, Singhesar, Gamarea, Lalgunge and Simralie. At Latipore there is a bazar for the boat traffic. That the aforesaid places represent the only marts over this large tract, shows how backward the people are in the scale of civilization. In the Punjab the smallest village has its petty trader.

The climate appears to be a mean between the damp heat of Bengal proper, and the dry heat of Upper India. At the end of April and beginning of May, fitful hot winds blow, but they last a very short time. There are no great extremes of temperature. Rice and marroea (a sort of millet) are the staple crops; of rice, a great variety of kinds are sown at various seasons of the year. Very few of the lands are "*do fusles*," *i. e.*, bearing two crops a year, and as a month may represent the time occupied in making rice nurseries, another month in ploughing and transplanting, another in weeding, and a fourth in cutting, the people have nothing to do for eight months of the year. Spring crops of wheat, &c., are grown in the tracts inundated by the Ganges; autumn crops in all other places. In June, the people subsist on mangoes. The deposits

of the floods of the Ganges are said to fertilize the soil; those of the Kosi to injure it. This would prove that the changes in the Ganges stream are very gradual; for where a deposit is due entirely to erosion, it must invariably be injurious to cultivation. Subsoil requires exposure to the air for a considerable time to effect the chemical changes necessary to make it a good surface soil. The bulk of the silt in the Ganges is surface soil, washed in by the rain. On the Dearah lands of the Ganges, *i. e.*, lands below flood level, magnificient spring crops are grown with little trouble. The large profits accruing therefrom, amply compensate for the risks from floods and changes of stream. As we proceed north, we find drainage lines become more defined, the land more undulating, and the high lands necessarily more sandy. About, and to the north of Soopole, high lands, owing to being so sandy, are usually looked upon as not worth cultivating. The soil and the rainfall correspond closely to what is found on the high lands of Goordaspore, and to the north of Umballa, and there very fair spring and autumn crops are grown. There are no winter rains. Nowhere is there to be seen careful cultivation, even near villages, the land is not devoted to growing garden vegetables, or the more valuable crops. One serious drawback is, that the district is overrun with Brahmins and Rajpoots. A despised mallie will pay Rs. 4 to 5 per acre with a profit to himself, where pauper proud Rajpoots will fight against paying eight annas. In a few cases, two crops are obtained on the high lands, but the outturn depends upon the caste of the cultivator, the lower castes being the most careful and energetic.

Most of the lowlands not liable to continued inundation, are well wooded with mangoe and palm trees, and clumps of bamboos, here and there land being set apart for the cultivation of thatching grass. There is a great want, however, of trees valuable for building purposes, but sál, toon, mahogany, sheesham and keekur or babul, flourish in these parts, as is proved by the specimens to be found in planters' gardens. A few years ago, large quantities of sál and toon were obtainable from the Nepál Terai, but Burmah teak from Calcutta is now more used, owing to the risks merchants have to run in dealing with the Nepálese.

No skilled labor is procurable in the district. Even at Soopole, (the sub-divisional Head Quarters,) there is not a carpenter or blacksmith. Here and there in important villages, one of the latter may be found, who can just manage to put a piece of roughly wrought-iron to the plough.

Coolies may be obtained in large numbers, at from 3 to 6 pice per day. They chiefly belong to the weaver caste, who have lost their trade through the cheapness of English cloth, and, as a rule, obtain their living by assisting as helps at harvesting, indigo manufacturing, &c.

Within the last ten years, a number of temples have been built by the more wealthy, some of the designs are very striking, but the effect is spoiled on closer examination, as the bricks are bad, and every ornament and projection is of plaster, like the icing of a Christmas cake. As these temples owe their construction to the desire of the wealthy to outdo each other, and not to a devotional feeling, there is no attempt to ensure permanence. The workmen brought from Monghyr and Durbhanga are quite capable of turning out first class work if required to do so.

Two rather expensive examples of embanking lands to save them from inundation were undertaken this year. The one, the Rajunpore bund, constructed at a cost to Government of Rs. 12,200, and calculated to protect 2,000 acres; the other, the embanking of the Dimra, at Mahessi, on both sides for six miles, costing about Rs. 8,000. Isolated attempts like these must prove costly, and are likely to yield unsatisfactory results. The best plan appears to be to obtain protection from inundation by embanked roads.

There are very ancient remains of an extensive fort and city to be found at Rajghát, and near Shapore are Mahommedan ruins. There are traces of the now extinct Bhar tribe, at Dorumtola, four miles to the east of Pachgachia. But the most remarkable monument of energy, centuries ago, is the Bír Bund, a section of which near Pertabgunge is given in *Fig.* 1.

Fig. 1.

Cross Section of the Bir Bund.



The great size of this bank at the present day, shows what a gigantic work it must have been. Starting from a low range, called the Sorunga hills in the Nepál Terai, it runs due south for 30 miles. Whether intended as a dyke to keep out the Kosi, or an imperial road, it is hard to say.

The rainfall of 1874 at Soopole is given below. It was most seasonable, and has produced a bumper harvest.

For week ending	MAY. No. of inches.	Rainy days.	Clear days.	For week ending	JUNE. No. of inches.	Rainy days.	Clear days.	For week ending	JULY. No. of inches.	Rainy days.	Clear days.
2nd,				6th,	3·29	4	3	4th,	8·11	6	1
9th,				13th,	7·37	2	5	11th,	3·90	5	2
16th,	Rains not commenced			20th,	3·15	4	3	18th,	1·77	3	4
23rd,				27th,	1·78	4	3	25th,	1·13	1	6
30th,	0 36	1	6								
Totals, ..	0·36	1	6		15·59	14	14		14·91	15	13

	AUGUST.			SEPTEMBER.				OCTOBER.			
1st,	0·60	5	2	5th,	4·24	4	3	3rd,	7·18	2	5
8th,	6·64	4	3	12th,	4·12	2	5	10th,	0·14	2	5
15th,	0·43	3	4	19th,	3·05	4	3	17th,	...	...	...
22nd,	0·35	3	4	26th,	2·99	3	4	24th,	...	...	...
29th,	1·23	4	3					31st,	...	...	...
Totals, ..	9·25	19	16		14·40	13	15		7·22	4	10

Total fall,	... ...	61·73
Clear days,	... ...	74
Rainy do.,	... ...	66
Heaviest falls,	13th June, ...	6·53
	8th August, ...	4·25
	26th September, ...	3·14

The following observations at places whose positions will be seen by referring to the Sketch Map, (*Plate* XI.,) will give a good idea of the spring level of the country.

Name of place.	Depth of spring level below surface of ground.			Remarks.
	In driest weather in April and May.	In the rains.		
		Depth.	Date of observation.	
	feet.	feet.		
Chandale, ..	12·00	6·15	12th August,	Well drained tracts.
Soopole, ..	12·00	9 00	13th „	
Peepra, ..	9·00	5·00	8th „	Here the rain is shed slowly.

Wells with a steining of burnt clay rings 2 feet 8 inches in diameter, are made at a cost of Re. 1, or at the most Rs. 2. Wells of from 5 to 7 feet in diameter, cost from Rs. 6 to 60 or more, according to the workmanship. Not a single appliance for raising water by animal power is to be seen in the district, the natives believing that bullocks are killed by walking in a circle.

It is generally believed that irrigation canals would avert a year of scarcity and famine; but it is doubtful whether in seasonable years they would be made use of to any appreciable extent, and then probably, as a rule, only by a few indigo planters; and any one who has had experience of canals knows that the net-work of village water-courses cannot be introduced at a moment's notice to meet a sudden lack of rain. In the Goordaspore district, Punjab, the spring level and rainfall are similar to what they are in this place. Now on the enhancement of the rates of the Bari Doab canal, the majority of the cultivators of Goordaspore preferred falling back on their wells, to taking canal water, it can scarcely then be expected that canals would be utilized here.

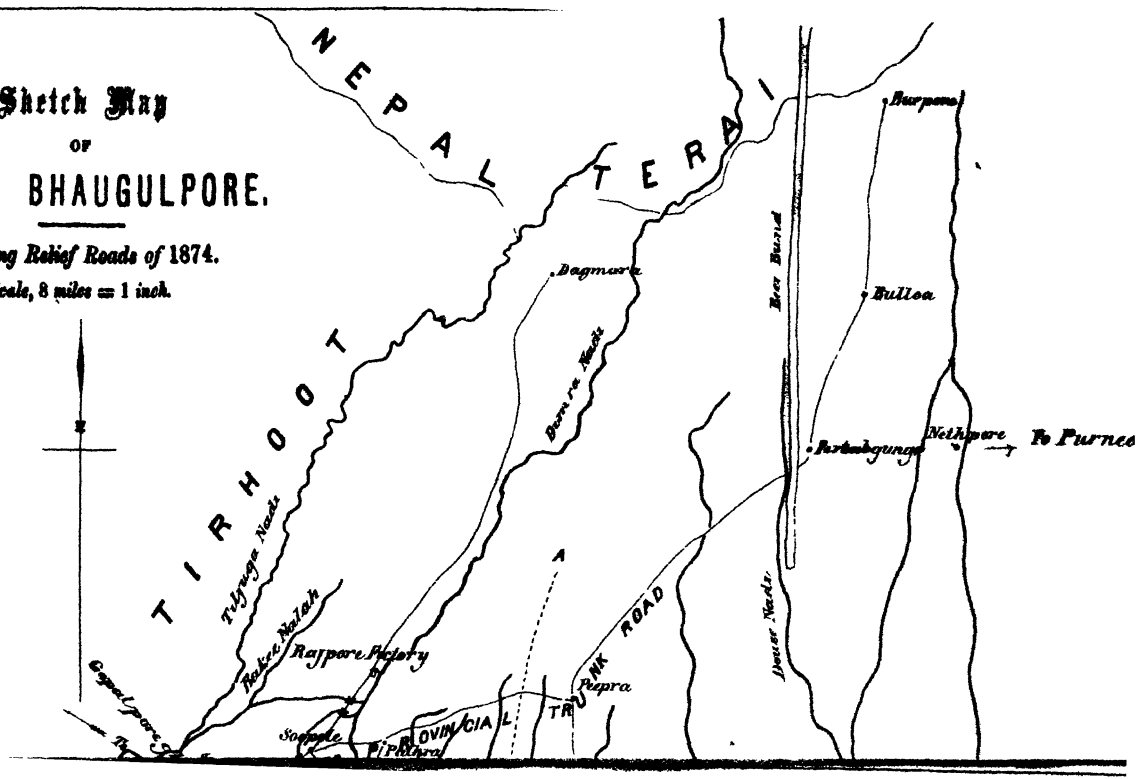
To the south of the Ganges from Mirzapore to Sahibgunge, the country is not an alluvial plain, but consists of the slopes of the Vindhya hills. The Soane canals traverse these slopes, where the spring level is in most places

PLATE XI.

Sketch Map
OF
NORTH BHAUGULPORE.

Showing Relief Roads of 1874.

Scale, 8 miles = 1 inch.

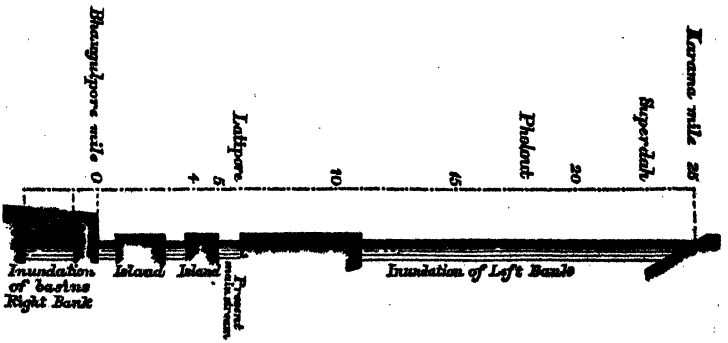


more than 40 feet below the surface. The soil is naturally well drained, and therefore dry, and being high ground, it is also sandy, and the trees are chiefly confined to the basins and hollows, where are to be found the best soil and most moisture. Here for the proper cultivation of the uplands, irrigation is a necessity. On the other hand, in North Bhaugulpore, we have an alluvial plain protected by large groves of trees, with prolific vegetation, and a spring level close to the surface.

It is just possible, that in time the absence of cold weather rains might make irrigation for spring crops popular, and for the certain cultivation of indigo it might be of great use; but as a safeguard against famine, it is scarcely needed. The distance from Bhaugulpore to Dagmara is 90 miles; that to Karama 25 miles, and allowing 3 miles for unculturable land on the Ganges in the cold weather, there are 22 miles of cultivation, or nearly 25 per cent. of the north of the district entirely independent of the rain-fall. The cross section of Ganges (*vide Fig.* 2) illustrates this. General

Fig. 2.

Cross Section of the Ganges at Bhaugulpore.



Strachey's minute on irrigation, demonstrates that a properly protected area of 25 per cent. is all that can be wished for.

Marvellous tales are told of the treacherous nature of the Kosi river and its violence. Its great floods are probably due to heavy rain in the outer ranges of the Himalayas, as all its floods are preceded by a change in the color of the water, due to the washings from the low hills, which gives warning of a flood at least a day before. That its deposits are not fertilising like those of the Ganges, is owing to the much shorter time the silt is held in suspension. On the Kosi, the silt could not be carried more

than 100 miles, on the Ganges it is carried hundreds of miles. The silt taken from the Ravee at Madhopore (where it issues from the hills) is not fertilizing, but 250 miles below it is. The constant changes in the river are due to the configuration of the country, and to the effects of the back-water of the Ganges in flood. A deep well defined channel and declivity are both wanting, to give a high velocity to the stream. With so many influences at work to disturb it, it may be expected that it abounds with quicksands, and consequently has acquired a very evil reputation. In a river with so ill defined a channel as the Kosi, changes of course are uncertain, as any petty obstruction or accident will cause them. This, however, would not make it expensive to bridge.

There appear to be no records of observations of the Ganges inundation. The discharge of the river has probably never been gauged below Allahabad. From Monghyr to Rajmahal, its right bank is permanent, owing to the rocky barriers presented by the Monghyr and Sonthal hills. On this bank are large backwaters, where the drainage from these hills fall into the river. The Ganges hugs its right and permanent bank, thus facilitating improvements on the left or north bank. Its left bank is simply an alluvial deposit. At Monghyr, where the river washes round a rocky promontory, the working stream is less than 2 miles wide, while at Bhaugulpore it is 6 miles wide, including islands. Immediately along the working stream, there is a thin strip of land more or less continuous, such as is found in all silt laden rivers running through alluvial deposits, which is above any but the very highest inundations. This strip varies in width from about 9 miles at Monghyr, to 5 miles at Bhaugulpore. Further inland again, there is in the rains the backwater of the Ganges, and the ponded up drainages from the north making a sheet of water from 12 to 16 miles wide.

A glance at a map of the country between Arrah and Rajmahal, will show that it is only rivers with large discharges that can force their way into the Ganges, without alteration of their general course; such are the Soane and Kosi. In the case of the smaller tributaries, such as the Boora Gundak and Tiljuga, the tendency of the rivers is to fill up their mouths, and prolong their channels parallel to its own indefinitely. The only limits to this prolongation of minor channels, is the meeting with rivers like the Kosi, or ponding up till the water rises above the thin strip of land that borders the working stream. Such being the case in making a road from

the left bank of the Ganges to the north, it is not absolutely necessary to bridge such streams as the Tiljuga, Bagmati and others, within the limits of the Ganges inundation. Making a bank across such channels is practically constructing a silt bar higher than any the Ganges can make.

In this portion of the course of the Ganges, the rise and fall must be very gradual, as may be seen from the following calculation.

From the cross section, shown in *Fig.* 2, we may calculate approximately sectional area of backwater as compared with sectional area of stream. The widths are nearly correct, but the depths in the absence of a series of soundings can only be approximate. Let d = mean depth of stream. The backwater on right bank is $1\frac{1}{2}$ miles wide, and $\frac{2}{3}\,d$ in depth; the backwater on left bank is 14 miles wide, and $\frac{1}{3}\,d$ in depth; and the stream itself is 2·75 miles wide, we have—

Sectional area of inundation, { Right bank, $1\frac{1}{2}$ miles $\times$ $\frac{2}{3}\,d$ = 1·
Left „ 14 „ $\times$ $\frac{1}{3}\,d$ = 4·7

5·7

„ „ Stream, ... 2·75 $\times$ d = 2·75

Wherefore sectional area of inundation is more than double sectional area of stream.

Again the Ganges basin is not less than 700,000 square miles, and as it may be assumed that over such a great area, local variations in rainfall will compensate one another, the inundation would be gradual and harmless, and not sudden and destructive, and the small declivity of the stream, about four inches per mile, must be taken into consideration. The flood levels of the Monghyr and Patna road, which runs parallel to the river give—

Mean 22,500	Red. District,	...	10,000	... 53·35	Mean 54·11.
	„	...	23,000	... 54·42	
	„	...	35,000	... 54·10	
	„	...	45,000	... 54·00	
	„	...	55,000	... 54·68	
Mean 167,500	„	...	1,35,000	... 60·44	Mean 63·20,
	„	...	1,45,000	... 63·01	
	„	...	1,65,000	... 61·07	
	„	...	1,85,000	... 66·00	
	„	...	2,00,000	... 65·50	

which gives a fall of 9·09 in 140,000 lineal feet, or nearly four inches per mile.

In road making in the Ganges inundation, we may take as examples of the two distinct methods of procedure required to be adopted on the right bank, the Bhaugulpore to Monghyr road parallel to, and the Sultangunge and Arjusgunge road at right angles to, the river. On the left bank, the Monghyr to Tirhoot road parallel to, and the Ganges to Madepore road at right angles to, the same, (*see* Sketch Map, *Plate* XI.)

The Bhaugulpore to Monghyr Road.—To make an embankment above flood level with no openings or bridges, would be to shut out the Ganges inundation, and interfere with local drainage. To provide bridges wherever a local drainage is intersected, would require the bridges to be so constructed, as to withstand the rush and outflow of the inundation, compared with which the local drainage would be inappreciable. So costly would this be, that it is doubtful whether it would be economical to aim at more than a fair weather track along such a line, seeing that water communication is available all the year round. In the case of the Railway, which runs alongside, ample bridging has been provided, and during the inundation, the water passes to the south of the line above, and returns to the river below Sultangunge. In this case, the inundation is really an arm about 20 miles long of the Ganges, the current being perceptible wherever the basin is contracted.

The Sultangunge and Arjusgunge Road.—This road from the 1st to the 3rd mile, passes through the Ganges inundation, and is provided with three timber bridges, aggregating a waterway of 480 running feet. The basin of water varies from 3 and 4, to 8 and 9 feet in depth. The spill of the Ganges takes place between Burriarpore and Sultangunge, (*see Plate* XI.,) so assuming the rate of declivity of the inundation to be the same as that of the river, the extra height of ponding up caused by having an embanked road with no openings, would be about 3·0 feet. This has to be reduced to 1·0 feet, since the water as it passes through the present openings has to attain a head of about 2·0 feet. It is, therefore, probable that the embanked and unbridged road, would not cause the inundation to rise appreciably higher. The local drainage could be dealt with by one or more culverts, constructed as substantially as an ordinary sluice.

The Monghyr to Tirhoot Road.—This road for 60 miles runs through the inundation of the Ganges. The principle on which it is constructed is,

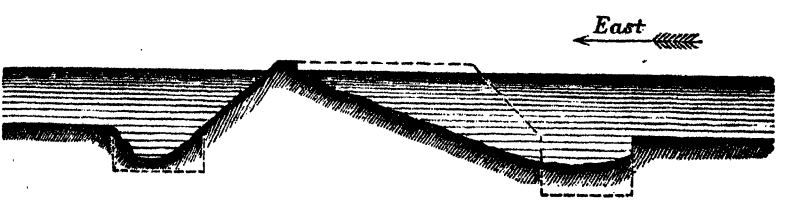
that all side channels of the river are bridged, culverts are provided for local depressions, and the bank in certain places is kept low, so as to be topped and breached by very high floods, and thus to save the bridges. It may be noted, however, that this plan was not approved of by the Chief Engineer. The idea appears to have been, to equalize as quickly as possible, the pressure of the flood waters on both sides of the road, but the result is, that it is little better than a fair weather track. It would probably have been more economical and certainly more useful, had the road been aligned, so as to get out of the inundation as soon as possible.

The Ganges to Madepore Road.—The following abstract of levels along the road, will give an idea of the very gradual rise of the country from the river.

Mile.	Red. Level N. S.	Mean flood level.	Remarks.
0	97·82	98·67	Inundated tracts with no defined declivity. It is worth noting that flood level rises as it recedes from the river. Mile 0 is at Lattipore—mile 44 at Madepore.
5	95·54		
10	88 22	96·70	
15	89 63	99·00	
20	95·15	99·57	
25	102·94		
30	107·39		
35	110·41		
40	120·00		

From mile 25 to 40, the rise is 17·06 feet, or a little over 1·0 feet per mile. This road commences at the Latipore factory, 6 miles north of Bhaugulpore. From the 0 to the 7th mile, it traverses the strip of land previously noticed, which is only covered in very high floods, and from the 7th to the 19th mile, the inundation proper. Owing to the prevailing wind being from the east, the eastern slopes are much cut up by the waves, and in some places the road is altogether washed away. *Fig.* 3

Fig. 3.



shows the section of the road where the depth of water is from four to

five feet. No berm being left between the bank and excavation pits, the waves break on the bank with their full force. The jungle and coarse grass that grow luxuriantly on the road, are sufficient to protect it from ripples of shallow water, but more substantial protection is required where the depth of water enables the waves to break on the slopes. A dowel, *vide Fig.* 4, would be useful, but scarcely permanent. If a part of the

Fig. 4.



berm was enclosed and planted with trees, they would probably be in a position to stand, without injury, the inundation of two to three months of the year, by the time the protecting dowel was washed down. The dowel proposed as a breakwater, should be connected with the road at intervals by transverse dowels.

It may be useful to give the results of trips from the north to the south, and from the south to the north of the Ganges, during the period of the inundation. From Soopole to Baktiarpore, there is nothing that cannot be easily remedied to obstruct cart traffic. Starting from Chiknaghat in boats (*vide Plate* XI.) at 8 A.M., on the 25th July, we arrived at Khagaria at about 6 P.M. We had to go due south, rowing in deep water, and poling in shallow water, and as the wind was from the east, we could not use awnings. On the 26th July, we proceeded about three miles by boat, through a spill channel of the Ganges, into the Boora Gundak, and at the end of the 3rd mile, we found the channel dry, owing to a fall in the level of the river. From here we had to proceed to the ferry three miles above Monghyr. The ferry boat, carried down by the stream, landed us at Monghyr in one hour. The route is shown in dotted lines. With an east wind, the Monghyr ferry boat takes half an hour, going from the left to the right bank. In the next trip from Bhaugulpore to the north, the boat (we started on the 2nd August) had to sail up the stream five miles, then drop down the central channel, and finally sail up the third channel to Latipore. This part of the journey took four hours. Latipore is at the first mile of the Madepore road and to the 7th mile there is no inundation. From the 7th

to the 17th mile, the journey takes nine hours. At the 17th mile, the embanked road being in good order, takes up the traffic for the remaining two miles of the inundation. It will be evident from this account, that the inundation, and not the river, is the great obstacle to easy communication between north and south Bhaugulpore.

Many valuable results would be obtained by preparing an accurate map on the plan shown in Sketch Map, (*Plate* XI.,) and tracing by numerous gauges down the river from Monghyr, the rise and fall of each, with reference to the rise and fall at Monghyr. In addition it would be also necessary to have good observations of the effect produced when the inundation commences, and when it subsides: something might be gleaned by tracing the alluvion and diluvion.

Pachyachia and Nowhatta Road.—This is a good specimen of the spasmodic way in which a native landed proprietor attempts to open out communications for his villagers. Work on a road is most energetically commenced—is as suddenly stopped—is not renewed—is a dead loss to the orginator—and of no use to the public. This road was made by a wealthy Brahmin, Nila Nand Singh, about four years ago. It is a bank from 5 to 9 feet high, with a roadway of about 14 feet, and no side slopes. It runs across the valley of the Dimra. It has three culverts, aggregating a waterway of 58 running feet for the spill waters of the right bank. These culverts are huge blocks of masonry, with small tunnels pierced in them; the lines of the blocks are not even square to the road, the masonry is of small bricks laid in an unlimited amount of shell lime mortar, but fortunately for the permanency of these works with a sluggish stream, the spill water does not require much waterway. Like all Zamindaree roads, it is furrowed by two wheel tracks, from 6 to 16 inches in depth, that make it very laborious for draught. Owing to the height of bank, and absence of proper side slopes, the safe working width of the road is only above 8·0 feet. All roads that can only be repaired at long intervals should have a width of at least 20 feet.

Drainages.—In the construction of roads, railroads and canals in the great plains of India, the most important question—as it requires a personal acquaintance with the country traversed—is the proper provision for the drainage. The following classifications of North Bhaugulpore drainage will, it is believed, meet all the cases excluding large and well-known rivers that are to be met with.

(*a*). Streams like the Tiljuga and the Dimra which rise in the Nepál Terai, have a permanent supply, and a well defined course.

(*b*). Streams like the Tilabah and Parwar, which, while having defined channels, depend entirely on the local rainfall.

(*c*). Flat swampy country like that between Singhessur and Pertabgunge, where the exact position of a culvert is immaterial.

(*d*). Sidelong ground of small extent, as may be met with south of Sookhpore, where the culvert provided must discharge sufficiently fast to prevent the road bank being topped.

The following shows the measured discharges of some of the streams.

TABLE A.

ber.	Name of stream.	Date of observation.	Mean section.	Mean velocity = 0·81 × surface velocity.	Discharge.	Hydraulic mean depth.	
1	Dimra on Soopole & Peepra road, ..	22nd June,	204	0·87	177	1·71	Slight breeze from the N. E.
2	Dimra on Soopole and Singhessur road,	15th August,	300	1·63	489	2·78	
3	Do. do.,	20th Septr.,	429	2·24	..	3·07	
4	Dimra on Pachgachia & Nowhatta road, ..	6th July,	832	0·81	969	2·08	Here the spill covers a great extent of country.
5	Parwan at Singhessur, ..	6th Septr.,	155	1·56	242	1·72	Area of its flood section is 297 sq. ft, and its hydraulic mean depth is 8·21. At this point, the stream does not spill over its banks.
6	Tiljuga, ..	8th August,	1,062	0·59	..	8·50	
7	Paridhar, ..	7th do.,	1,089	0·31	..	8·71	
8	Tiradhar, ..	8th do.,	480	..	..	5·33	Velocity scarcely perceptible.

In bridging the Tiljuga or Dimra, it is not necessary to provide head way for the water traffic, as it is of no importance. A break of 15 to 20 days of clear weather, will make the Dimra too shallow for a boat drawing more than 1·0 to 1·5 feet.

TABLE B.

Flood sections of Dimra (Singhessur and Soopole Road).

Lettering of Section.	RIGHT BANK.			CHANNEL.			LEFT BANK.		
	Area.	W. P.	H.M.D.	Area.	W. P.	H.M.D.	Area.	W. P.	H.M.D.
	sq. ft.								
A, B, ...	1,131	400	2·83	1,040	120	9·08	279	120	2·33
C, D, ...	1,844	400	4·61	1,142	130	8·79	2,087	800	2·42
E, F, ...	752	400	1·38	976	110	8·87	328	90	3·64
	3)3,727	1,200		3)3,158	360		3)2,694	1,010	
Mean, ..	1,242	400	3·11	1,052	120	8·78	898	337	2·66

By Neville's formula, the flood discharge can be obtained from the observed discharge as follows:—

$$D : D_1 :: CA \sqrt{\frac{R}{S}} : CA_1 \sqrt{\frac{R_1}{S}}.$$

Where D_1, A_1, and R_1 are values taken from observation 2, Table A., and A and R from Table B.

$$429 : D :: 300 \times \sqrt{2·78} : 1,053 \sqrt{8·78}$$

$$\therefore D = \frac{1053 \times 2·96 \times 429}{300 \times 1·668} = 3,057 \text{ cubic feet per second.}$$

Discharge of spill on right bank as per figures in Table B.

For a hydraulic mean depth of 3·11, the mean velocity according to the observation No. 3, Table A., would be 2·24 feet nearly.

Therefore discharge = 1,242 × 2·24 feet = 2,781 cubic feet.

Discharge of spill on left bank as per Table B.

The hydraulic mean depth being 2·66, the mean velocity according to observation No. 2, Table A., would be 1·63 feet nearly.

Therefore, discharge = 898 × 1·63 feet = 1,463 cubic feet, and total discharge would be—

Channel discharge = 3,057
Spill of right bank = 2,781
„ left „ = 1,463

Total, ... 7,301 cub. ft. per second.

This flood section of the Dimra is shown in *Fig.* 1, *Plate* XII. The four

observations of the Dimra given in Table A., are instructive, as showing how strikingly the discharge varies in different reaches. No. 1 is taken near Pathra, (*vide* Sketch Map, *Plate* XI.,) where the stream runs through a tract of lowland, with a spill into the Bati stream. Owing to this, the observed mean velocity is 0·87, instead of being 1·32, due to a declivity equal to that in observation No. 2. Nos. 2 and 3 taken west of Bina, show high velocities, and a flood discharge of 7,301 cubic feet per second, whereas No. 4 taken 10 miles further down, shows only a velocity of 0·81, and a discharge of 969 cubic feet per second, with the level of the water at time of observation only 1·0 feet below flood level. The style of country—more swampy than in section No. 1, will be seen from Sketch Map, The estimated flood discharge at this point is 1,635 cubic feet. There is no spill between, but on the contrary a portion of the spill above Pathra, a considerable drainage from the east, fall into the Dimra between the point of observation Nos. 2 and 4. It follows that much more expensive bridging is required 10 miles above, than at this place. Judging from appearances, the opposite conclusion would be arrived at.

The following is an illustration of a simple method of calculating the waterway of a bridge in this particular case of the Soopole and Singhesur road, with least disturbance to the stream.

The hydraulic mean depth of the channel is 8·78, and therefore omitting fractions, the depth of the water on floor of bridge should be 9·0 feet ($= d$).

The mean velocity (v) of *channel* discharge is 3·8 feet per second, therefore running feet of waterway $= \frac{D}{v \times d} = \frac{3057}{9 \times 3\,8} = 90$ feet nearly $= 6$ spans of 15 feet each.

Flood openings or culverts for spill waters.—The hydraulic mean depth of right bank is 3·11, and therefore depth of water may be 3·5 feet, and as a casual rush of water through a road masonry culvert with small openings can do no harm, the velocity may be taken at 5 feet, which is obtained by a small amount of heading up, or afflux of about 1·2 feet, therefore running feet of waterway required is $= \frac{2781}{5 \times 3{\cdot}5} = 170$ feet nearly. For left bank it is $\frac{1463}{5 \times 3{\cdot}5} = 90$ feet nearly. Further and more minute surveys would determine how far this *maximum waterway* may be reduced, and how much ponding up may be allowed. Moreover a longer bridge and less length of culvert would be cheaper, but not to be recommended.

NOTES ON NORTH BHAUGULPORE—BENGAL.

Fig. 1.

BRIDGING THE DIMRA.

Scale for Masonry, 450 to 1.

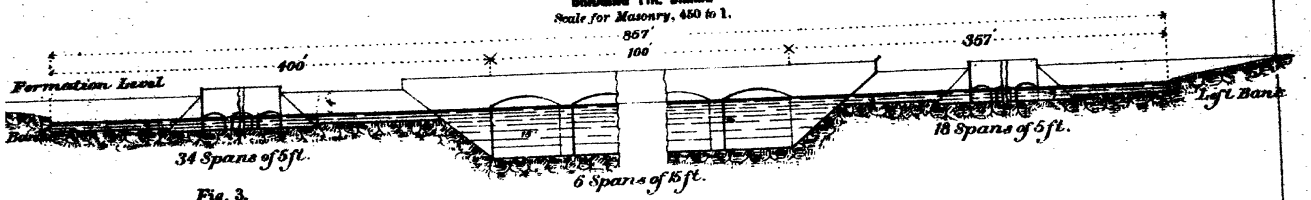


Fig. 3.

EMPORARY CROSSING FOR LOCAL DRAINAGES.

(Soopole and Peepra Road, Parwan Nallu).

Scale { *Horizontal, 1200 to 1*
Vertical, 300 to 1.

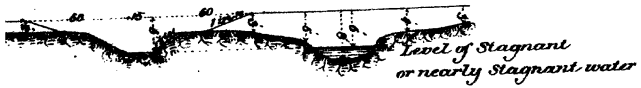


Fig. 4.

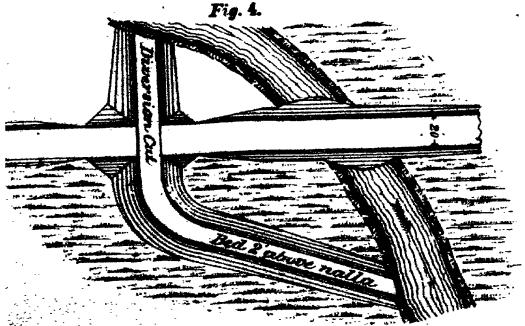
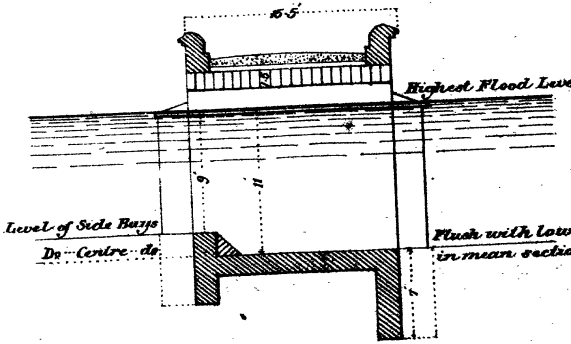


Fig. 2.

CROSS SECTION

150 to 1.



PLA

In fixing the level of flooring and springing lines, the datum line is highest flood level. If navigation is not to be provided for, springing lines of all arches should be at level of highest flood mark. The floorings of centre bays, or bays should be flush with lowest depth of bed in *mean* section; the floorings of abutment bays should be below highest flood mark, a depth equal to the hydraulic mean depth, and the intermediate bays should be stepped down to meet central one. This arrangement prevents the stream from ever taking the bridge in flank. The floorings being arranged as given in *Fig.* 1, *Plate* XII., and the depth of the head wall of each bay being the same, we have—

(*a*). Economy in up-stream foundations at abutments.

(*b*). Greater discharging power.

(*c*). The flooring and not the down-stream earthen bed is exposed to the action of the afflux.

(*d*). The deep stream is forced through the centre bays.

TABLE C.

NAWAB SALAR JUNG BAHADU

Flood Sections of the Tiljuga and its affluents.

	RIGHT BANK			CHANNEL.			LEFT BANK.		
	Area.	W. P	H M D	Area.	W. P.	H.M.D	Area.	W. P.	H.M.D.
Tiljuga, ...	3,276	1,800	1·82	1,614	127	...	1,177	375	3·13
Paridhar, ...	11,250	3,000	3 75	1,749	136	...	4,000	1,000	4·00
Tiradhar, ...	3,360	1,520	5 50	944	102	...	3,900	1,500	2·60

The Paridhar is a spill channel of the Tiljuga. From the exceedingly small velocities, it might be thought that the inundation affected these streams at Mahesi, though this place is 32 miles above Monghyr. But in March last, two months before the river could affect the Tiljuga, it appeared to be a very sluggish stream. In observations 6, 7, and 8 of Table of Discharges, comparing velocities with hydraulic mean depths, shows that very little provision is required for culverts for spill waters. In the case of the Tiradhar, that a bunded road through it would only require three or four small sluices.

Temporary drainage crossings.—It is evident that all local drainages

can only have a running stream during, and for a shorter or longer period after, a fall of rain. In such cases, a culvert is only a necessity on first class roads. The present plan of leaving gaps in the road bank in the lowest part for drainage, will be found on examination to be a mistake. For instance, take the crossing of the Parwan nullah on the Soopole and Peepra road, (*Figs.* 3 and 4, *Plate* XII.) The road happens to cross at a reach of the stream where the bed is for half a mile or more, nothing but a long trough, retaining a quantity of water long after the drainage has been passed off. In such a case, the traffic has to ford even when there is no perceptible velocity. Obviously the remedy is to bank the road across the drainage, making a diversion cut with the level of its bed, at such a height as to ensure a running stream as long as there is drainage to be run off. It is evident that the diversion cut will be dry soon after the rain has ceased. The new bed being more often dry will be less miry than the old one. The higher the diversion bed, and the wider it is, the less depth of water to be forded. If the bed and ramps are paved with lumps of burnt clay, or any other hard material that may be available, the ford will never obstruct traffic. These fords could be used at all places where the depth of water in diversion did not exceed one and a half, or at the most two feet. The following is a simple rule for determining section of diversion cut—

Let x = depth of bed of diversion cut below maximum flood level.

A = Mean area of flood section of drainage channel.

a and x = Mean area and mean velocity at time of observation.

v = Mean velocity of drainage channel in flood.

y = Mean width of diversion cut.

t = Mean velocity permissible in diversion cut.

Then $y = \frac{A \times V}{a \times t}$.

This method of obtaining V is indicated in the calculation of the Dimra, and the smaller v is compared to hydraulic mean depth, the more ponding up may be allowed to reduce width of diversion cut.

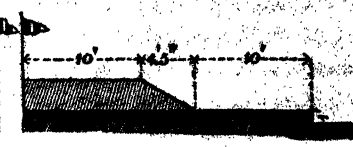
Road Sections.—(In *Figs.* 5, 6, 7 and 8, half sections only are shown). In raising a bank, the usual thing is to throw the earth from the centre outwards. Although the undressed bank thrown up in this manner may be allowed to settle during a whole rainy season, the earth that has to be thrown in to fill up gaps in the sides and slopes will not bind

with the weather worn slopes of the undisturbed stuff below formation level. Along either side of the road, there will be what are called "faults," if a term borrowed from Geology is permissible. The result is that a fall of rain finds out these faults, and cuts deep ravines in the road. It often takes years of annual repairs to eradicate these "faults." This difficulty is recognised in heavy embankments by throwing the stuff in concave layers. A much simpler plan, however, is to run dowels along the outside, as shown in what is called the *weathering* section, (*Fig.* 5.)

Fig. 5.
Weathering.



Fig. 6.
Dressing.



In this section, the "faults" will conduct the water to the centre, and not to the outside of the bank, although the dowels may not be consolidated to any great extent by the trampling of the workpeople. The dowels should be made somewhat higher than formation level, so that in dressing the earth may be thrown from the outside to the inside, and thus obtain section, (*Fig.* 6). In section (*Fig.* 7), the turfing is shown overlapping

Fig. 7.
Turfing.



Fig. 8.
Final Section.



the road by one foot. By laying down the lines for the turfing from the centre line, any errors in dressing are remedied, and the workmanlike appearance of the road maintained. The overlap of the turfing prevents water from peeling off the freshly laid turf. The surface of the road is now complete, and one good fall of rain will consolidate it, but make it useless for traffic. The next step is to lay a rectangle of earth still working from the centre line of the road on the top, and dress it down, so as to obtain the section shown in *Fig.* 8. All the other steps can be completed at any time of the year, and the last one after the first heavy fall of rain.

The repairs of the road-bank will depend after this on the wear and tear of traffic, and not appreciably on the rainfall. Where the road passes through very sandy soil, the best stuff available, even if it cost something more, should be used for the dowels, and the hearting filled up with what can be obtained alongside.

Arranging and lining out a network of roads.—In the hilly country to the south of the Ganges, the obstacles to communications are steep and rocky slopes and trees. The drainages pass off the rainfall so rapidly that water is a minor obstacle. On the flat plains of the north, the obstacles are cultivation, swampy ground, and the larger drainages. As a first step, the obstacle caused by cultivation is disposed of by marking off the ground that is to form the public highway. Swampy ground, the most important obstacle, is remedied by a bank of earth. As for the larger drainages, they are isolated obstacles that do not cause that great wear and tear to carriage, that swampy country does. In North Bhaugulpore, they carry the loads across stream in canoes or on men's heads, and swim the carts and bullocks across. In the case of the roads in the neighbourhood of Soopole, (*vide* Sketch Map, *Plate* XI.,) we find the following errors :—

(1). On the road from Soopole to Dagmara, we find there timber bridges of from 80 to 100 feet waterway over the spills of the Dimra. An examination of the country shows that the spills might have been banked across, and the cost (about Rs. 60 per running foot) of bridging saved.

(2). It will be seen that the three roads from the east might have been lined out, so as to cross at Bina. Here one bridge would answer for the roads without making the roads much longer.

In converging roads, it is certainly economical to throw one into the other, even though the angle of intersection be great. The Soopole and the Peepra road, should have met the Dagmara road two miles North East of Soopole. A road can depart considerably from a straight line without increasing its length appreciably. In a new country the shortness of the route is not so desirable as a surface easy for transport.

BHAUGULPORE,
8th November, 1874. } E. A. S.

No. CXLVI

EXPERIMENTS ON CEMENTS AT BANGALORE.

A Report by SURGEON E. NICHOLSON, B.M.S., *on Special Duty, D. P. W.*

Bangalore, 20th Nov., 1873.

HAVING completed my cement-testing machine, and other contingencies, I began a series of experiments with a view of ascertaining what results could be obtained with such materials as are at the disposal of every Engineer, viz., brick, lime, and sand, before attempting the employment of new materials.

After many preliminary experiments, I settled upon the following tests for the quality of mortars and cements.

Tensile strength was determined on the standard bricket adopted by the Metropolitan Board of Works. This bricket of 7½ inches long (it may conveniently be shorter) and 1½ inches thick, is 3 inches broad at each end, the middle portion for a length of 1½ inches being only 1½ inches broad, thus presenting in the waist a section of 2¼ square inches. The broad ends are held by two clips which are pulled asunder by a gradually increasing strain until rupture of the bricket takes place; this strain can be applied in various ways, preferably by a lever machine. The instrument used in the Board of Works trials and that of Hervé-Mangon are levers of the first kind; the machine I use is a lever of the second kind, in which the disruptive force is applied to the lower clip of the bricket, the upper being suspended from a strap passed over the upper beam of

the square frame. This machine answers perfectly well, and tested with weights is of considerable exactitude; it was made up for me by an Indian-blacksmith at a cost not exceeding Rs. 100.

At the beginning of October I received the Michele's patent cement-testing machine from England. I have no appliances for testing it with weights; but I can readily understand that, the indications are comparatively rough, and not to be relied on within 15 or 20 lbs. The graduation of the arc is necessarily arbitrary, for while the counterpoise is rising along it, the short arm of the lever is traversing another arc of very different radius, and the friction of the axle tends to dullen the indication. The index slips back with the fall of the counterpoise, instead of remaining steady; I have remedied this by attaching a friction pad of India-rubber to the back of the index. The check bolts connecting the clips are liable to jam, and I should prefer them to be of less diameter. The bricket moulds supplied are of a form adapted to the peculiar clips of the machine; the waist of the bricket, instead of being square in section for a length of 1½ inches, is bi-concave at the sides, so that the standard section of 2½ square inches is only found at one point. This modification, though convenient in some respects, appears to favour the bricket by throwing the line of rupture off from the narrowest part of the neck. Whichever be the cause, the dulness of the machine itself, or the form of bricket, one thing appears certain, that the machine is only adapted for cement to the exclusion of miscellaneous compositions; that above 300 lbs. it gives a higher tensile strength than is shown by lever machines with the old form of bricket, and that the error increases with the weight indicated. The following comparative experiments were made with brickets from the same batch of cement, and in series of not less than three, the average of which was taken:—

	Age.	Lever Machine.	Michele's.	Difference.
	Days.	lbs.	lbs.	per cent.
1 Cement, 1 Sand, ...	8	334	313	− 6
Cement neat, ...	7	345	365	+ 6
Do.	7	399	446	+ 12
Do.	28	437	581	+ 33
Do.	28	483	607	+ 26
Do.	34	557	635	+ 32

Adhesive strength was determined by the force required to tear asunder a joint made between two good bricks. I adopted the system of crossed bricks used by Colonel Sotten, U.S.E. The bricks used were those made by the Sappers and Miners, excellent for ordinary work, and indeed far superior to any other brick I have seen in Bangalore. I have lately used some very superior bricks made by the Sappers and Miners expressly for the work; they are made of washed clay and felspar. The bricks being 4¼ inches broad, a cross-joint presents a surface of 18 square inches. They were joined under the pressure of a man leaning heavily on the uppermost, and after a certain interval they were tested in the same machine that was used for breaking brickets. The bricket strap being slid aside, was replaced by two stirrups, which supported the ends of the upper brick, whilst two other stirrups, a plate and hook, connected the lower brick to the lever of the machine. By the addition of a small lever, having only 20 lbs. preponderance, below the large lever, I have enabled the machine to test the weakest mortars as well as the strongest. Adhesive strength varies of course with different materials; as it is much less than the tensile strength of the mortar-joint, it is not interfered with by the latter; the adhesion yields long before the joint itself, though a person seeing the joint broken from the shock, and from the adhesion having yielded simultaneously on either side, might think the joint itself gone, and that the adhesion of parts of the joint to the surface of the brick showed the adhesion to be stronger than the joint. This is a common error, but a moment's reflection on the great tensile strength of mortars compared to their adhesive strength will show that this is an error. The tensile strength of a mortar joint is on the average about seven times greater than its adhesiveness to the surface of the brick which it joins, and it would therefore appear that the objection made by Major (now Major-General) H. D. Y. Scott, R.E., to Sir Charles Pasley's tests (viz., that the breaking weight of a joint "is a measure of the tenacity or adhesion of the mortar alone, or partly of its cohesion and partly of its adhesion" is ill-founded. But even were the weight required to tear a brick joint asunder affected by the tensile strength of the mortar, the test would still be of great value from its practical application to the quality of the mortar for brick-laying purposes.

The setting of the mortar under water is an important point. When

the mortar is packed in a confined space, the rapidity of setting may be taken as a measure of hydraulic energy. But when the mortar is placed under water without support, as in the form of a ball, another property, hydraulic plasticity, becomes apparent. Portland cement, though setting far more rapidly than soorkee mortar, yet possesses much less hydraulic plasticity; a ball of cement (at least of the sample I worked with), will not stand if immersed in less than two hours after it was made, while soorkee mortars have generally sufficient plasticity to enable them to stand immediate immersion. And some hydraulic limes, which possess sufficient plasticity to stand immersion in the shape of a ball, yet do not set hard for two or three weeks. The hydraulic energy of a lime or mortar is generally tested by the time required before a cake of the mortar immersed at once will support the weight of a loaded needle. Unfortunately this instrument has not been of a very uniform nature in the experiments extant. While Vicat's original needle was, I believe, 2 millimetres (·078 inch) in diameter at the flat point and loaded with one kilogramme (2·2 lbs.), other diameters and weights have been freely used. Gillmore mentions two needles, one of $\frac{1}{12}$-inch diameter loaded with $\frac{1}{4}$ lb., and another of $\frac{1}{24}$-inch diameter loaded with 1 lb. Mr. Dejoux does not describe the needle he uses, but he quotes French specifications in which a needle of $\frac{1}{24}$-inch, loaded with 10 oz. is used, as a test for the hydraulic value of lime. I use myself Gillmore's two needles, the light one for ascertaining the 'soft' set, and the heavy one for the 'hard' set, the lime or mortar being contained in a small chatty of about 2 inches diameter, such as are obtainable in the bazaar at the rate of four annas a hundred. These needles are useful, but I attach little importance to their indications comparatively with the numerical indications given by the adhesive strength of brick joints. Unless a lime is strongly hydraulic one may have to wait for days before any indications of setting take place. I prefer to join one or more pairs of bricks, immerse them at once, and test the breaking weight of the joints after 24 hours, and after seven days or even 28 days, and I believe that Engineers desiring to test the quality of a lime will find this practical test far preferable to the needle test.

I use, then, but two processes for ascertaining the value of a lime or mortar, viz., the bricket test for tensile strength, and the brick-joint test for adhesive strength and hydraulic energy. I prepare with each composition six or more brickets, and from nine to twelve brick joints, and sub-

ject these to the following probation in air or water previous to trial in the machine:—

	Probation.		Day of trial.	Indication.
(*a*). *Tensile strength.*	In air.	In water.		
8 Brickets, ...	28 days (in dry box)..	..	28th, ..	Value for dry concrete and plastering.
3 Brickets, ...	1 day (in damp box)	27 days,	28th ..	Value for hydraulic concrete.
(*b*). *Adhesive strength.*				
3 Brick joints, ..	28 days (open shade)	..	28th, ..	Value for ordinary brickwork.
3 Do.		28 days,	28th, ..	Value for hydraulic brickwork.
(*c*). *Hydraulic energy.*				
1 Brick joint,.. ..	..	1 day,	after 24 hours	Hydraulic energy.
1 Do.	..	7 days,	8th day,	Do.

In the case of feebly hydraulic mortars the brickets cannot be immersed so soon as 24 hours after making; seven days or even one month must elapse; and it is also necessary to defer the immersion of the brick joints for one to seven days. In special cases it may also may be well to try the effect of immersing joints made with cement or strongly hydraulic lime after one day in air, and thus to ascertain the gain or loss of strength by the delay in immersion.

The series of experiments now submitted, and the detail of which is appended, includes many preliminary experiments, and is not so systematic as I should wish; moreover, having for a long time but few bricks capable of standing more than 20 lbs. per square inch in the adhesive strength experiments without peeling, I was obliged to allow the bricks weakened by immersion to dry for six or seven days before they could be tried; this exposure being favourable to the brick, but generally unfavourable to the mortar. Having now explained the principles on which these experiments were conducted, I may proceed to give the results obtained. Quantities are always given in parts by measure, unless otherwise specified. Lime is measured in the state of paste, as the volume of slaked lime produced by a given bulk of lime is variable, and measurements in quick lime are inconvenient. The volume of paste is the active volume

of the lime when in combination with other materials; it is very constant, and does not differ greatly from that of the quick-lime, being about equal to it in stone-limes, and about ⅓rd greater in shell and other fat limes.

Experiments on Mortars of Shell-Lime and Sand.

The shell-lime commonly used for works near the Indian coasts may be taken as the type of the fat limes of India, as chalk-lime is that of the fat limes of Europe; both chalk and shells consist of nearly pure calcium carbonate. The shell-lime which I used was sent me by the District Engineer, Presidency. Its specific gravity in bulk was ·86; it slaked in 15 minutes after being watered, nearly doubling in bulk: specific gravity, ·55. The slaked lime, passed through a seive of 45 meshes to the inch, gave 22 per cent. of siftings, principally unburnt shell, and 78 per cent. of fine lime; this latter, specific gravity in bulk, 0·5, contained on analysis—

1·7 foreign matters (brick dust, &c.)
12·4 calcium carbonate.
85·9 calcium hydrate.

100

The slaked lime required its weight (half its bulk) of water to become a paste, the volume of which was 1½rd that of the quick-lime, ⅔rd that of the slaked lime. The sand used was good Bangalore pit-sand, principally formed from the decomposition of the gneis rock. In some of the experiments it was sized by sifting; sand not passing through a seive of 35 meshes being considered as coarse. From the experiments detailed in the Appendix, Series A., I deduce the following conclusions.

The strength of a mortar of fat lime and sand is owing nearly entirely to the effect of desiccation. As long as it is kept damp, it acquires no strength, and when dry (for it does not 'set') although hard and even resonant on the surface, it crumbles into powder directly the carbonated crust is broken through. Some effect is produced by the gradual combination of the sand and lime under favourable circumstances, such as sharpness, fineness or porosity of sand, as exposure to alternate damp and dryness after the first drying has taken place; but these effects are very irregular and so slow, that after 30 years they are barely perceptible.

This is clearly shown by the following table, in which the average and

best mortars of my experiments are contrasted with mortars tried by Captain Smith, Madras Engineers (quoted in the Roorkee C. E. College Treatise), and by Sir Charles Pasley:—

	Age.	Adhesive strength. lbs. per square inch.
Series A., average mortar, 3 sand,	28 days	2·8
Do best do., 1½ sand,	Do.	4·6
Captain Smith's do., 1½ sand,	13 years	
Chatham lines, best mortar, ...	30 years	

If this strength, even at 30 years old, be compared with that of n it will be seen that the comparison is by no means favourable to the of sand mortar of fat lime. (Bricks joined with the mud formed ordinary loamy soil of Bangalore, showed in six days an adhesive st of 5·3 lbs. per square inch. A joint of the same mud, but pointed ⅛th inch deep with good soorkee mortar, and left exposed to the weather, gave after three months an adhesive strength of 7·3 lbs. per square inch).

This mortar is not only entirely devoid of hydraulic properties, and incapable of hardening in a damp atmosphere, but if submerged before complete desiccation has taken place, the adhesion already acquired will disappear. This may happen after seven days, and even after 28 days, but the strength will sometimes re-appear on subsequent desiccation. During immersion the strength is all but in abeyance.

The best results were obtained with one part of lime-paste to 1½ of sand, but as much as three parts of sand may be used without great deterioration. Sand requires about ·4 of its volume of water to saturate it; we may therefore infer that 1 part of lime-paste will just fill up the intervals of 2½ parts of sand; it is, however, hardly safe to allow no more lime than will be just sufficient to fill up the intervals; therefore the proportion of 1 to 2 will be found more generally applicable. Practically, it will be found that sand moistened and mixed with ⅓rd of stiff lime-paste hardly increases in volume.

The hardening of the mortar being entirely due to desiccation, it is not necessary that the bricks should be soaked in water. When a hydraulic mortar is used, the bricks should be saturated by at least one hour's im-

mersion before being laid, but in the case of mortars of sand and fat lime, saturation of the bricks appears to be positively detrimental; it is sufficient if they are dipped into water for a few seconds immediately before laying.

Experiments with Mortar of Sand and slightly Hydraulic Lime.

These experiments, detailed in the Appendix, Series B., were made with a lime made at Kistnarajpur, near Bangalore, and procurable in the bazaar. It is in small nodules of a pinkish gray colour, which becomes greenish gray when powdered, resembling Portland cement in colour. In bulk its specific gravity is ·95; powdered it is 1·0, when slaked the volume increases less than one-third, and the specific gravity is ·80. The slaked lime requires one-third of its bulk of water to become a paste, returning to the original volume of the quick-lime. The slaked lime was found to contain—

12·3	insoluble silicates.
8·8	calcium carbonate and silicates.
78·9	calcium hydrate.
100	

This lime may be taken as the type of the moderately rich kunkur limes of India; and being able to get it fresh, I made several series of experiments with it. It is generally very badly burnt, owing to the high price of fuel near Bangalore, and in this case, yields a large quantity of 'kuppy,' or unburnt refuse, when slaked and beaten. Its price is rarely less than one rupee per parah of 2½ cubic feet, but although one parah does not yield much more than its bulk of slaked lime after deducting the 'kuppy,' the slaked lime is sold at little more than half the price of the quick lime; it is probably much adulterated. For concrete work, the whole lime, after slaking, may be ground into fluid paste; but for brickwork it must be separated from the 'kuppy,' or ground 'quick' and then slaked.

This class of limes will not bear so much sand as shell-lime; as a rule not more than two parts of sand should be used to one part of lime, quick or in paste. Nevertheless some unusually good results were obtained with three parts of sand, of which one part, fine, was added first, the two other parts, coarse, being subsequently incorporated. The adhesive strength is from 5·8 to 8·9 lbs. at 28 days' old not immersed; the tensile strength 20 to 50 lbs. per square inch.

Mortar made with this lime resists the action of water, and even improves under it, but in proportion to the lapse of time allowed before immersion. The tensile strength of the mortar especially improved by immersion after complete setting in air. Brickets giving only 24 lbs. per square inch after four weeks in air, attained a strength of 62 lbs. by immersion for another four weeks.

Experiments with other Hydraulic Sand mortars.

I have only been able to examine a few of the limes yielded by limestones already analyzed; this part of the work I reserved until I should have completed the preliminary experiments on typical materials. The results obtained from some of these limes are detailed in the Appendix, Series C., and may be summarized as follows:—

Bhowany, Kotamunglum.—This limestone contained 60·9 per cent. of silicates, 29 of calcium of carbonate, and 6·1 of magnesium carbonate. It is friable, in large blocks, and I marked it "too meagre." I was, however, somewhat surprised to find, on burning half the sample, that a joint made with the lime, neat, gave the great strength of 19·9 lbs. per square inch. The lime does not slake, it should be ground and used as a cement.

Kolar No. 1, from Beirandhully on the Palar river. This nodular limestone contains 20·5 per cent. of silicates, 59·4 of calcium carbonate, and 5·3 of magnesium carbonate. The lime from it gave good results. Mortar made with two parts of sand showed after 28 days an adhesive strength of 16·1 lbs. per square inch, dry, and 13·1 immersed. Tensile strength 72 lbs.

Kolar No. 2, from Baitmunglum on the Palar river. This nodular limestone contains 17·9 per cent. of silicates, 76·2 calcium carbonate, and 6·5 of magnesium carbonate. Mortar made with the lime which it yielded and two parts of sand, gave an adhesive strength of 6·6 lbs. per square inch, dry, and 51·1 lbs. immersed. Tensile strength 46 lbs. per square inch, dry and 61 lbs. immersed.

Limes made from the specimens of limestones sent from Palghat, Coimbatore, and Secunderabad were only slightly hydraulic. In many limestones want of homogeneity prevents them from showing, when burnt, the hydraulic properties which their chemical composition seems to indicate.

Experiments on the addition of sugar to mortars.

The addition of raw sugar or jaggery to the shell-lime mortars made in Madras has often been mentioned, but I have never seen the rationale of its employment correctly stated. In Burnell's treatise on limes and mortars, the use of sugar is ascribed to its influence in retarding setting. In the Roorkee Treatise, it is stated that the bad qualities of fat limes "may be in some degree corrected by it, as its influence is very marked in the first solidification of the mortar. Captain Smith (Professional Papers, Madras Engineers), attributes the fact that mortars made of calcined shells have stood the action of the weather for centuries to this mixture of jaggery in their composition." That the sugar has some action is shown both by my own experiments, and by those of Captain Smith recorded in the Roorkee Treatise.

	Age.	Mortar without Sugar.		Mortar with Sugar.	
		Adhesive strength lbs per square inch.	Tensile strength lbs. per. square inch.	Adhesive strength lbs. per. square inch.	Tensile strength lbs. per square inch.
Captain Smith's, 1 lime 1½ sand,	13years.	4·5	Twice the adhesive,	6·5	Equal to the adhesive.
E. N., Series D., ...	28 days.	3·1	8·2	5·6	11

These experiments accord fairly, and show that while some improvement doubtless attends the use of sugar, it is not so great as has been supposed. I have observed no difference in the solidification of the mortars made with, and without, sugar, except that the former take a sort of glaze on the surface. The reason of the beneficial action of sugar is, I consider, to be found in the greatly increased solubility of lime in a saccharine solution. Whilst water dissolves only about ·1 per cent of lime, a moderately strong solution of sugar will dissolve as much as 3 per cent.; it is evident that the desiccation of the sugar solution will tend to strengthen the mortar by allowing the lime to crystallize, besides placing it in a more favourable position for combination with the sand. Ulteriorly the sugar probably becomes converted into carbonic acid and water, another cir

stance tending to strengthen the interior of the mortar. It is quite impossible that sugar can act by retardation of the setting, for such action is decidedly unfavourable to a mortar which hardens not by setting, but by desiccation. It may also be noted that while sugar improves limes of sand and fat lime which harden only by desiccation, it is utterly destructive of the setting properties possessed by a mortar of soorkee and fat lime. A mortar composed of 1 shell-lime, 5 soorkee, which showed an adhesive strength of 6·5 lbs. per square inch only stood 1·1 lb. when made up with jaggery water, and the tensile strength of 110 lbs. per square inch fell to 20 lbs.

Experiments on the addition of Silicate of Soda, or of Alum-cake, to Mortars.

The silicate of soda or of potash, known as 'soluble glass,' has been proposed for imparting hydraulic properties to fat limes. In Gillmore's treatise, it is stated that this result "may be obtained by forming this hydrate (of lime) into a paste, with a requisite proportion of silicate of soda." My expectations were disappointed, for the mixtures which I made were quite worthless. The same disappointment occurred in the case of alum-cake (a commercial sulphate of alumina prepared from clay and containing silica). I had hoped that the formation of calcium sulphate, aluminate and silicate would ensue on the mixture of this substance with fat lime, and that hydraulic properties would thus be imparted; but the experiment was a failure.

Experiment on mortars of Lime and Soorkee.

After obtaining the results detailed in the Appendix, Series E., I cannot but be surprised that the valuable properties of artificial puzzolana, made by pounding brick or other forms of burnt clay, should have been so neglected, although so well known. Whatever be the cause of the alleged failure of mortars made with this puzzolana when subjected for years to the action of sea-water, nothing has ever been proved against them for ordinary building or for inland hydraulic works. It has been alleged that sand produces a cheaper, harder, and stronger mortar. This is erroneous; except in the case of strongly hydraulic limes, which are by no means common, the use of soorkee instead of sand increases beyond comparison the strength of the mortar even for ordinary building purposes, whilst the objections of increased cost and inferior hardness are founded on a mistake,

On the question of strength there is no comparison, as a glance at the results detailed in the Appendix will show; and as regards hardness and cost, the combination of soorkee and lime can be hardened by the addition of sand just as plain lime can, while the decrease in the proportion of lime required to produce a mortar or concrete of superior strength more than compensates the difference of price between soorkee and sand. Taking, for example, the case of a shell-lime mortar made with one part of lime to two of sand, this will be found quite hard on the outside, but directly the outer crust is broken, the whole crumbles away; its tensile strength is about 8 lbs. per square inch, and it is utterly devoid of hydraulic properties. But if the shell-lime be mixed with three parts of soorkee (a material which can never hardly cost one-fourth the price of lime), the resulting mortar or rather cement will obviously be much cheaper, bulk for bulk, than the original lime (the cost being, say, that of 1 parah of lime against that of $\frac{1}{4}$th parah of lime and $\frac{3}{4}$ths parah of soorkee—the latter rarely costing more than $\frac{1}{3}$rd the price of lime). Now, this cement which, if used neat for brickwork, is at least four times as strong as either pure lime or lime mixed with sand, besides improving considerably by immersion can be mixed with twice its volume of sand forming a mortar or concrete, the tensile strength of which is 120 lbs. per square inch, fifteen times that of sand mortar, while it is equally hard and much cheaper. The soorkee cement used, unmixed with sand, as a mortar in brickwork, is not dearer than sand mortar, inasmuch as the quantity of soorkee which can be used without loss of strength is greater than that of sand; moreover, the plastic nature of the soorkee cement permits of joints being made with less than half the quantity which would be used in the case of sand mortar. This advantage is best shown when the bricks have fairly true surfaces, and considering the slight difference of price which there should be between well moulded bricks and badly moulded bricks, it is worth while taking care that these should be as good as possible. Good table-moulded bricks use much less mortar than ground-moulded bricks, besides being much stronger. Even when the weak and rough ground-moulded bricks are alone available, there is yet considerable pecuniary economy in the use of the soorkee cement, inasmuch as the proportion of lime in it can be diminished to less than half that which would be safe in sand mortar without the strength falling below that of the latter, or even of the bricks themselves.

Soorkee cement should then be diluted with sand in order to obtain hardness with little loss of tensile strength, as in the case of concrete, but as a rule with soorkee, if the weakness of the bricks renders weakening of the mortar justifiable as a measure of economy. Very good hydraulic concrete may thus be made with only one-twentieth of lime in materials (1 lime, 3 soorkee, 6 sand, 10 gravel) and hydraulic mortar may contain as little as one-fifth or one-sixth of lime.

The soorkee I used was of two kinds: one was the ordinary Sappers and Miners brick (marked S. and M.) pounded; the other was the common country brick made near Bangalore, a very weak and roughly made article. These gave results nearly equally good, far better than those obtained with a soorkee made of fine washed clay. Soorkee made with broken pottery (of the black kind made with blue clay and paddy husk) gave also very good results. In each case the soorkee was passed through a seive of 45 meshes to the inch.

The advantage of combining soorkee with lime is best shown in the case of fat lime; the more hydraulic the lime is naturally, the less is the advantage of soorkee. When lime possesses hydraulic properties, sand-mortar can be used for works which will not be at once subjected to the action of water, but in every case the substitution of soorkee for sand improves the strength of the mortar, makes it set much more quickly, and enables it to resist at once the action of water. A firm set is obtained in three days when the work is immersed at once, while a mortar of moderately hydraulic lime and sand will rarely set firm under water in less than three weeks.

Soorkee cement answers well for plastering, it takes a polish equal to that of sand chunam, while it is far more durable and impermeable, and its strength is not dependent, as in the latter, on the surface remaining sound. The colour is buff or reddish and somewhat irregular if the work is done in hot dry weather, but where the work can be protected from the sun, as inside houses, the colour would probably remain uniform, and it would be more agreeable than the glare of white.

The theory of the action of soorkee is based on the fact that the silicates of alumina forming clay are rendered more easily decomposable by heat. Clay is not acted on by acids in the cold, but when burnt it is nearly entirely decomposable. The manufacture of artificial or concentrated alum (sulphate of alumina) is founded on this property. Clay is reduced to a fine powder and roasted, it is then treated by dilute hot sulphuric

acid; aluminum sulphate is formed and silicic acid set free. An analogous action takes place in the mixing and setting of soorkee cement; the lime attacks the clay rendered decomposable in burning, unites with the silicic acid to form silicates, and probably also combines with the liberated alumina. A good soorkee cement is then a silicate of lime analogous to Portland cement, and, like it, capable of hydrating and solidifying independently of atmospheric action. If the proportion of soorkee be sufficient to supply silicic acid to all the lime present, and the mixture well made, the composition is totally different from that of sand mortar; it is a true cement capable of setting of itself even under water, instead of a mixture of lime and sand hardening by desiccation and by the action of atmospheric carbonic acid on the outer surface. When the lime used in a sand mortar is hydraulic, it is true that some silicate is ultimately formed, even under water; but there is considerable inconvenience attending this secondary action, as the conditions which enable the great excess of lime to harden are unfavourable to the setting of the silicate, and *vice versâ*. In the very strongly hydraulic limes known as 'intermediate' (between limes and cements), this antagonism becomes dangerous, as the silicates are apt to set before the free lime becomes hydrated, and this reversal of the usual sequence of actions causes the disintegration of the set mortar. The use of soorkee fortunately renders the Engineer independent of the quality of the lime he uses; whether it be fat lime or hydraulic lime the effect is the same; the results may be somewhat superior with the latter, but against this advantage there must be considered the plasticity of the fat lime and the facility and economy of working with it. On the whole I believe that when good and fine work is required, equal strength can be obtained with fat lime, provided that care be taken in the preparation of the cement. This is especially shown when the superior material about to be described is used in the place of common soorkee.

Experiments with the improved Puzzolana or Limed Soorkee.

While the addition of what may be termed the natural soorkees (those prepared from bricks or burnt clay) to any ordinary lime affords a cement greatly superior to sand mortar both in strength and in hydraulic energy, yet the setting is slow when compared with that of Roman (natural) or Portland (artificial high-burnt) cement. A soorkee cement takes 72 hours to acquire the same firmness which Portland cement attains in 15 to 24

hours, and it is, therefore, a desideratum to find if soorkee could not be improved so as to set more rapidly. The idea which presented itself to me, in order to obtain greater hydraulic energy, was the preparation of the clay in some manner which would render it still more readily decomposable when mixed with lime. For this preliminary attack, the use of a small quantity of lime suggested itself; the addition of such a quantity as should disaggregate the clay, and by its action both in the wet way and by heat, transform the clay into highly acid silicates, capable of taking up their full quantity of lime when hydrated, then becoming neutral or basic silicates.

My experiments on this point are far from complete, as I have yet to ascertain the proper amount of lime to effect this action, the heat which should be used in burning, and the best way of using the soorkee. As far as I have proceeded, I have obtained results which promise success. The best results have been given by a soorkee made of the pottery clay and ten per cent. of lime (by weight, quick). Five per cent. give indifferent results, twenty per cent. seems somewhat better than ten per cent., but the experiments are not complete. The results detailed in the Appendix, Series G., promise, I think, ultimate success. It would appear that by the use of soorkee made with bricks of common clay mixed with lime, common fat lime can be made into a cement possessing greater adhesive strength than the best bricks, and when made into concrete, equalling concrete of Portland cement in its tensile strength, and in its rapidity of setting under water. The best results for adhesive strength were given by one part of lime paste to one of ten per cent. limed soorkee; this does not set very quickly, but in 28 days attains a strength of 31·1 lbs. on the square inch (1,122 lbs. on a pair of bricks lengthways). With three parts of soorkee the setting is much more rapid, the joint attains an adhesive strength of 2·8 lbs. per square inch after 24 hours under water, 16·5 lbs. per square inch in seven days; after this there is little or no increase. With four parts of soorkee the strength fails. The best concrete or mortar is made by combining two parts of soorkee with one of lime paste, and then adding an equal volume of sand. This mortar, containing $\frac{1}{6}$th of lime, attains in 28 days (the 27 last under water) a tensile strength of 171 lbs. per square inch, and it also answers well for brick work, as it sets nearly as rapidly as the cement without sand, and attains in 28 days under water (immersed immediatly) an adhesive strength of 16·6 lbs. per square inch. With three

parts of soorkee to one of lime, the concrete made by the addition to the cement of its volume of sand, is somewhat superior in tensile strength, attaining 158 lbs. per square inch after 28 days (the 27 last under water).

Another sample of this kind of soorkee (unfortunately made in small quantity only) gave the best results I have hitherto obtained: one part of shell-lime paste with three of the soorkee gave an adhesive strength of 37 and 34 lbs. per square inch; and one part of fat stone lime with three parts, half of ordinary soorkee and half of limed soorkee, gave 35 and 36 lbs. per square inch. In three out of the four experiments, the joints did not give, the bricks yielded, though they were such hard bricks that a bricklayer had great difficulty in chipping them with the trowel. I would, however, mention that I cannot, as yet, definitively claim a superiority for this limed soorkee over ordinary soorkee, as the latter has sometimes given extraordinarily good results; but taking the experiments all round, the best results have been obtained by the use of limed soorkee, and it undoubtedly possesses greater hydraulic energy.

Experiments with Country-made Cements other than Soorkee Cements.

Besides the coment made by combination of puzzolana or soorkee with lime, there are others which may be divided into the following type:—

(*a*). Roman or Boulogne cement, from naturally argillaceous limestones burnt at a low temperature.

(*b*). American cement, from naturally argillaceous magnesian limestones burnt at a low temperature,

(*c*). Portland cement, from artificial argillaceous limestones burnt at the highest temperature.

(*d*). Lime and clay cement (twice kilned) burnt at a low temperature.

The first of these may possibly be made in India, as it would seem that in Bengal (Soane district) suitable marly limestones are found; a drawback to their use is the necessity of the composition being constant, and the structure homogeneous; this would especially be felt in India where skilled superintendence is not always available. Limestones requiring frequent analysis to enable their composition to be rectified are hardly suitable for the Indian manufacturer.

The second kind does not seem to be common in India; it could be artificially produced by the aid of the deposits of magnesite found both in Southern India and in Bengal; it is possible that an artificial composition

of magnesite lime and clay would yield good results when burnt; this, however, comes under the head of the fourth method.

The third method is ill-adapted to India. The so-called Portland cement is a cement made (with a slight variation from Vicat's original process) from clay and chalk very intimately mixed and burnt at such a high temperature, that the proportion of clay can be reduced to a very low point. The excess of lime is forced into combination with the clay forming very basic silicates. Its production requires clay and chalk at a nominal cost, good coking coal at a low price, skilled labour and facilities for employment of machinery. The failure of one of these conditions renders the manufacture costly, perhaps a losing speculation. Now in India there is no chalk, coal is either dear or inferior, the use of machinery expensive, skilled labour often precarious. The first of these objections is fatal to any competition with the cement imported from Europe. The hard limestones of India could not possibly be pulverized to the degree of fineness requisite for the perfect combination of the materials without an expenditure which would put all competitors out of the question.

The fourth method is the most promising. It is Vicat's first process, and is well adapted for countries where the limestone is too hard to be reduced to sufficiently fine powder for the manufacture of cement by his second process. It was recognized by Sir Charles Pasley as good, and Indian experience has confirmed the value of this twice-kilned lime cement. From the Roorkee Civil Engineering College Treatise, it appears that this cement was used successfully on the Madras Eastern Coast Canal, and also at Singapore. The increased cost from the use of lime instead of limestone in this process would be compensated by the economy in grinding, and the lesser heat required. The chalk and clay (Portland) cement requires a white heat, and its clinker is very hard and expensive to grind, while the lime and clay cement is burnt at a low red heat, and the kilned cement is as readily ground as chalk. The facility of preparation from materials to be obtained nearly everywhere, the low temperature in burning, the ease with which the burnt cement can be ground are strong recommendations, and it only remains to be seen whether this could not for most purposes supersede imported cement.

The proportions recommended by various experimenters vary considerably, and are somewhat confused by the variable specific gravity of lime, quick or slaked, and of clay, wet or dry.

The following are some of the proportions hitherto used—

	By Measure.			By Weight.	
	Lime.		Clay, wet.	Lime, quick.	Clay, wet.
	Quick.	Slaked.			
Sir Charles Pasley, ...	(1	...	1·1)	1	2
Roorkee experiment, ...		Same.		Same.	
East Coast Canal, ...	7	...	5	(1	1·2)
	or 1	...	·71	...	...
Singapore (Captain Man), ...	...	5	2	...	...
	or 1	...	·62	(1	1·1)
Vicat's, ...	(1	...	·158)	1	1·05
E. N., Series H., ...	1	...	·77	1	1·3

One advantage of this cement is, that the proportion of lime can be diminished, so that any degree of energy can be given to it. In Gilmore's treatise, it is stated that the 10 per cent. of clay (added to 100 parts of lime) will confer moderately hydraulic energy, while it will never be necessary to exceed 54 per cent. to produce a very active cement. This last proportion ·54 by weight of clay to 1 of lime, corresponds with the quantity indicated by Vicat's proportions by measure, and is probably not far from the exact number. Sir Charles Pasley's cement seems to have been over-clayed. In the above Table I have calculated weight from measure and *vice versâ* on the assumption that the specific gravity in bulk of quick lime was ·85, of slaked lime ·55, of wet clay 1·45.

In my experiment detailed in the Appendix, Series H., I obtained very good results, an adhesive strength of 21 lbs. per square inch on dry joints (after 28 days), and 25 lbs. on joints immersed after three days; but only 12·5 lbs. when the joints were immersed at once. An experiment at Roorkee with Sir Charles Pasley's proportions, gave a cement showing an adhesive strength of 10 lbs. per square inch after 14 days under water. The cement would appear to be not so suitable for work requiring immediate immersion as the more plastic cements of lime and soorkee; but the use of a light-clayed composition used with soorkee would perhaps answer better. I shall resume experiments on this composition.

If to the lime and clay a suitable proportion of magnesia (burnt mag-

nesite) were added, it is probable that the cement would show some of the properties of the American natural cements, so well known for their power of resisting the action of sea-water.

Comparative experiments with the above detailed compositions and with Imported Cement.

In order to obtain a standard of comparison for the foregoing experiments, I made a series of trials with Portland cement. When the barrel was opened, the cement came up to the Board of Works standard, and when diluted with sand, the results were rather better than those recorded by Mr. Grant in his trials with a cement of higher quality; the breaking weights in lbs. per square inch, are given in the following Table :—

	Mr. Grant's Experiments.		Series I.	
	7 Days.	1 Month.	7 Days.	28 Days.
Cement, neat, ...	202	308	181	220-228
„ 1 sand, ...	44	140	..	143
„ 1¼ „	..	..	..	123
„ 2 „	23	56	..	78
„ 3 „	12	26	..	62
„ 4 „	..	14	..	..
„ 5 „	..	10	..	37

The adhesive strength of Portland cement is affected by dilution with sand even more than the tensile strength; the contrary is the case when it is diluted with soorkee, the tensile strength becoming greatly affected, while the adhesive strength comparatively little impaired, and the hydraulic energy even increased. There is, however, no reason for diluting Portland cement where adhesive strength is required; any apparent economy is counterbalanced by the increased thickness of joint required, and the strength descends to level of that of a common soorkee and lime cement. As a rule, the use of Portland cement in brickwork is a waste of money. The value of Portland cement is in its great hardness and its tensile strength, and to obtain these, the cement must be used neat. Where great hydraulic energy and plasticity are required, the admixture of an equal proportion of soorkee will be found useful; it doubles the adhesive strength in the first 24 hours when the cement is used under water for masonry or for stopping springs.

In the case of Marine works, it would appear prudent to use Portland cement whenever the cost is not excessive, until soorkee cements are cleared from the charge (though a disputed one) of being attacked by sea-water. But the superiority of the limed soorkee appears to be so great, that there is a strong probability of its being able to resist the action of sea-water like the natural puzzolana of Italy. If such should be the case, the use of cement made with it would effect an enormous saving in construction of Indian harbour works. It will be seen that the strength of this cement increases by the addition of a moderate proportion (one or even two parts) of sand, and by immersion, so that a mortar for concrete *(béton)* making may be obtained with it equal to that of Portland cement and sand, as regards hydraulic energy and strength, and at a small fraction of the cost. The following is a rough estimate of the cost of 100 cubic feet of sand mortar, and of concrete made with these different materials, the proportions being taken from actual experiments.

Common soorkee cement with one part of sand.

			RS.	A.	P.
	Tensile strength, 172 lbs. per square inch.				
18	Cubic feet quicklime, at 3½ annas, ...		3	15	0
55	„ common soorkee, at 1¼ annas, ...		5	2	6
60	„ sand, at ¼ anna, ...		0	12	0
	Cost of 100 cubic feet, ..		9	13	6
	Cost of 100 cubic feet of moulded or rammed concrete.				
50	Cubic feet of the above mortar, ...		4	14	9
100	„ of stone or ballast, ...		3	2	0
			8	0	9

Limed soorkee cement with one part of sand.

	Tensile strength, 171 lbs. per square inch.				
25	Cubic feet quicklime, at 3½ annas, ...		5	7	6
50	„ limed soorkee, at 2½ annas, ...		7	0	6
60	„ sand, at ¼ anna, ...		0	12	0
			13	4	0
	Cost of 100 cubic feet of moulded or rammed concrete.				
50	Cubic feet of the above mortar, ...		6	10	0
100	„ of stone or ballast, ...		3	2	0
			9	12	0

Portland cement with one part of sand.

		Rs.	A.	P.
Tensile strength, 143 lbs. per square inch.				
66 Cubic feet cement, at Rs. 14 per cask of 5 cubic feet, ...		184	12	0
66 „ of sand, at ½ anna, ...		0	13	0
		185	9	0
Cost of 100 cubic feet of moulded or rammed concrete.				
50 Cubic feet of the above mortar, ...		92	12	6
100 „ of stone or ballast, ...		3	2	0
		95	14	6

The cost of Portland cement I have taken at the Bombay market price of three months ago. The above estimate is of course rough, but it shows that the cost of the materials of moulded concrete blocks would, in the case of Portland cement, be about ten times greater than when lime and artificial puzzolana are employed.

E. N.

Note by the Lieut.-Col. Mullens, R.E., Chief Engineer for Irrigation.

Fort St. George, 8th January, 1874.

Surgeon Nicholson's report, contains much matter of interest on the subject of cements, and the record of the experiments made will be of considerable use to all those members of the department who are capable of applying the results obtained, from the use of the materials upon which Surgeon Nicholson has experimented, to the probably different materials which may be available for use in the several districts and ranges of the Presidency. What is chiefly required is definite information as to the best means of employing particular limes on the principal descriptions of constructive work on which the Public Works Department is engaged. For instance, the information regarding the use of burnt clay or soorkee with shell-lime is very valuable, and in Madras and other localities in which this description is alone, or most generally, employed, it is advisable that no time should be lost in introducing a mixture of burnt clay with the lime, which will then be much improved both as regards strength and hardness. Surgeon Nicholson's remarks regarding the non-setting of fat

limes and sand, and their want of hardness below the surface are confirmed by daily experience.

What the Public Works Department requires is—

1*st*.—A cement which will set with reasonable rapidity either under water or in very wet positions, and possess fair adhesive strength.

2*ndly*.—A cement which will be strong and hard in superstructures.

For foundations for hydraulic works generally, bridges across rivers, &c., an hydraulic cement is really essential. Where springs are not very troublesome, a very quick setting cement is not generally needed, because the water-level can be kept down by baling for two or three days without difficulty, but where the work has to be executed under water, or where springs are abundant, rapidity of setting is necessary to prevent the cement remaining soft or being washed out. I have myself made cement which set perfectly under water. At the Nellore Anicut works in 1857-58, concrete foundations were laid in the water, and in that particular instance the cement was made of 1½ parts burnt clay and 1 part slaked lime, reduced to powder, made into balls, and re-burnt. After 48 hours immersion the concrete was found to be very hard. The clay used was of a dark blue, very compact, greasy, description. No experiments were made on its tensile and adhesive strength. In Tanjore, in 1862-63, similar proportions were found to answer very well with the lime and clay obtainable at the Lower Coleroon Anicut. Lately, at Dowlaishweram, the same proportions have given excellent results, with however air drying for two days before immersion of the brickets and concrete blocks. Some brickets of the 2¼ square inch cross section at the neck, which had been thus treated, were taken out of the water and tested, the breaking weight being about 375 lbs., and considering that the materials had been very imperfectly ground, the tensile strength exhibited may be considered very good. Here the burnt clay and slaked lime were mixed without subsequent reburning. Further experiments are in progress to ascertain the effect of reburning, as also that of mixing raw clay with slaked lime and burning the mixture. Concrete blocks made with cement of 1 lime, 1½, and 2, clay, respectively, give excellent results as regards strength and hardness, and it was found very difficult to break them up with a heavy hand-hammer.

What District and Range Officers now need to be told is the best way to make the most of the several descriptions of lime available with

reference to the dry or wet situations in which the cements and mortars are to be employed. It may be found also that some of the limes, of which samples have been forwarded, are not adapted to any constructive work, and are not capable of being improved sufficiently by any admixture to render them trustworthy; and, if so, it will be well to discontinue their use altogether. In the Coimbatore District, on the Ambravatty Anicuts, I noticed that fat limes had been used, and that the mortar had never set properly, but had dissolved out from the masonry to a very great extent, and the remedy is undoubtedly to be found in the mixture of proper proportions of burnt clay or soorkee with the lime for the future. Again, on the Madras Irrigation and Canal Company's Canal, much of the leakage through culverts and aqueducts is due to the use of fat limes without the necessary mixture of clay. Another notable example of the advantage of mixtures of chunam with other materials may be observed in the case of chunam floors. It is a common practice to alternate black and white squares, and the former generally wear much better than the latter, owing to the fact that the surface in the white squares is pure chunam, and, in the black, a mixture of lamp black or burnt cocoanut shells with chunam. For plastering near the coast, great advantage will be derived from the mixture of clay and lime to form the cement, and as a matter of appearance too the grays resulting from the mixture, which may be varied by the addition of a little red or yellow ochre will be an improvement on the glaring white of new plaster of the ordinary kind, and on the dirty look of the surface after a few months' exposure.

J. M.

APPENDIX.

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets.	Age. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength, lbs., per square inch.	Tensile strength, lbs., per sqr. inch.
		SERIES A.—*Mortars of shell-lime and sand.*								
48	2	1 lime, 1½ sand ..	Joint	28	..	..	28	83	4·6	..
	1		,,	22	21	6 4/24	28	49	2·7	..
	1		Bricket	28	..	..	28	22	..	10
49	3	1 lime, 2½ sand, ..	Joint	28	..	..	28	57	3·1	..
	1		,,	22	21	6 4/24	28	20	1	..
	1		Bricket	28	..	..	28	18	..	8·2
52	2	1 lime, 3 sand, ...	Joint	28	..	..	28	42	2·3	..
	2		,,	28	21	7	56	82	4·1	..
	1		Bricket	28	..	..	28	11	..	5
53	2	1 lime, 4½ sand, ...	Joint	28	..	..	28	15	·8	..
	1		,,	5	..	..	5	7	·4	..
	1		Bricket	28	..	..	28	10	..	4
115	5	1 lime, 3 sand, ...	Joint	28	..	..	28	50	2·8	..
	3	(In this and the following	,,	56	..	..	56	47	2·6	..
	1	the lime paste was made		..	21	7	28	25	1·4	..
	1	from slaked lime, un-		1	21	6	28	30	1·6	..
	1	sifted).		2	21	5	28	10	·5	..
	1			4	21	3	28	..	..	..
	3			7	21	..	28	..	..	..
	3			28	28	..	56	9	·5	..
124	6	1 lime, 3 sand, No. 35, ..	Joint	28	..	..	28	48	2·6	..
	1	(Sand sifted through No.	,,	7	14	..	21	13	·7	..
	2	35 sieve).	,,	7	14	7	28	40	2·2	..
	3		Bricket	28	..	..	28	18	..	8·2
	1		,,	7	14	7	28	23	..	10
125	3	1 lime, 3 sand, No. 45, ..	Joint	28	..	..	28	37	2	..
	1		,,	7	14	..	21	8	·4	..
	1		,,	7	14	7	28	57	3·1	..
	2	(Kept in a box), ..	Bricket	28	..	..	28	14	..	6·2
	2		,,	28	..	..	28	26	..	11·4
126	3	1 lime, 3 sand, No. 60, ..	Joint	28	..	..	28	54	3	..
	1		,,	7	14	..	28	11	·6	..
	1		,,	1	20	..	21	8	·4	..
	2		,,	7	14	7	28	72	4	..
	3		Bricket	28	..	..	28	25	..	11

APPENDIX.—(*Continued*).

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets.	Age. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength, lbs. per square inch.	Tensile strength, lbs. per sqr. inch.
SERIES A.—*Mortars of shell-lime and sand*—(Continued).										
127	3	The same left 24 hours,	Joint	28	..	..	28	55	3	..
	1	then beaten up, ..	„	7	14	..	21	17	·9	..
	1		„	1	20	..	21	13	·7	..
	2		„	7	14	7	28	49	2·7	..
	1		„	1	20	7	28	30	1·7	..
128	2	1 lime, 2 sand, No. 60, ..	Bricket	28	..	..	28	48	..	21
	4		„	28 in box.	..	..	28	34	..	15
	2		„	18	10	..	28	12	..	5
	2		„	18	10	14	42	37	..	16
SERIES B.—*Mortars of stone-lime (Bangalore) and sand.*										
77	1	Lime, net, ..	Joint	28	..	..	28	119	6·6	..
142	3		„	..	28	..	28	27	1·4	..
78	2	1 lime, 1 sand, ..	Joint	28	..	..	28	109	6	..
	1		„	..	21	7	28	125	6·9	..
	2		„	28	21	7	56	190	10·5	..
	2		Bricket	28	..	..	28	117	..	51
80	2	1 lime, 2 sand, ..	Joint	28	..	..	28	115	6·4	..
	2		„	28	21	7	56	256	14·2	..
	1		Bricket	28	..	..	28	55	..	24
81	4	1 lime, 3 sand, ..	Joint	28	..	..	28	161	8·9	..
	2	(1 fine sand mixed first; then 2 coarse sand),	Bricket	28	..	..	28	47	..	21
	2		„	30	32	9	71	142	..	62
143	3	1 lime, 1 sand, No. 60,	Joint	28	..	..	28	111	6·1	..
	3		„	..	28	..	28	16	·9	..
	3		„	56	..	..	56	96	..	..
	2		„	28	28	..	56	90	..	..

APPENDIX.—(*Continued.*).

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets.	AGE. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength, lbs. per square inch.	Tensile strength, lbs. per sq. inch
SERIES B.—*Mortars of stone-lime (Bangalore) and sand*—(Continued).										
141	3	1 lime, 2 sand, No. 60,	Joint	28	..	..	28	124	6·9	..
	3		„	7	21	..	28	92	5·1	..
	1		Bricket	28	..	..	28	40	..	17
	3	(in damp box).	„	28	..	..	28	..	..	..
	1		„	7	21	..	28	25	..	11
SERIES C.—*Mortars of shell-lime and sand with the addition of sugar, &c.*										
50	4	1 lime, 2¼ sand, made with water containing 5 per cent. of sugar, ..	Joint	28	..	..	28	102	5·6	..
	1		Bricket	28	..	..	28	25	..	11
123	3	1 lime, 3 sand, ..	Joint	28	..	..	28	53	3	..
	3	5 per cent. jaggery in water, ...	Bricket	28	..	..	28	37	..	16
	3			56	..	..	56	38	..	17
129	3	1 lime, 2 sand, No 60, ..	Joint	42	..	..	42	67	3·7	..
	3	5 per cent. jaggery in water, ...	„	18	24	..	42	12	·6	..
51	3	1 lime, 2¼ sand, ...	Joint	28	..	..	28	54	3	..
	1	5 per cent. silicate of soda in water,.. ..	„	..	21	7	28	25	1·4	..
	1		Bricket	28	..	..	28	16	..	7
54	3	1 lime, 2¼ sand, ...	Joint	28	..	..	28	32	1·8	..
	1	5 per cent. alum cake in water, ...	„	..	21	7	28	..	..	..
	3		Bricket	28	..	..	28	30	..	13
SERIES D.—*Mortars of shell-lime and soorkee.*										
94	3	1 lime, 1½ S. M. soorkee,	Joint	28	..	..	28	181	10	..
	2		„	..	21	7	28	370	20·5	..
	3		Bricket	1	21	6	28	136	..	62
95	1	1 lime, 2 S. M. soorkee,	Joint	28	..	..	28	156	8·6	..
	3		„	..	21	7	28	200	11·1	..
	1		Bricket	28	..	..	28	217	..	99
	3			1	21	6	28	200	..	91

APPENDIX.—(*Continued*).

No.	No. of Trials.	Composition lime measured in paste.	Brick-joins or brickets.	Age. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength lbs. per square inch.	Tensile strength, lbs. per sqr inch.
		SERIES D.—*Mortars of shell-lime and soorkee*—(Continued).								
96	3	1 lime, 3 S. M. soorkee,	Joint	28	..	..	28	139	7·7	..
	3		„	..	21	7	28	306	17	..
	1		Bricket	28	..	..	28	150	..	66
	3		„	1	21	6	28	172	..	77
	1		„	1	21	44	66	417	..	185
58	1	1 lime, 3 S. M. soorkee,	Joint	28	..	..	28	125	·7	..
	2		„	1	21	6	28	485	2·7	..
	1		Bricket	1	21	6	28	210	..	95
97	3	1 lime, 4 S. M. soorkee,	Joint	28	..	..	28	102	5·6	..
	3		„	..	21	7	28	181	10	..
	3		Bricket	1	21	6	28	256	14·2	..
102	3	1 lime, 5 S. M. soorkee,	Joint	28	..	..	28	116	6·4	..
	3		„	..	21	7	28	161	9	..
	1		Bricket	28	..	..	28	243	..	110
	3			1	21	6	28	212	..	90
104	3	1 lime, 7 S. M. soorkee,	Joint	28	..	..	28	80	4·4	..
	3		„	..	21	7	28	89	5	..
	2		Bricket	28	..	..	28	136	..	62
	3		„	1	21	6	28	126	..	57
110	3	1 lime, 10 S. M. soorkee,	Joint	28	..	..	28	63	3·5	..
	3		„	..	21	7	28	79	4·4	..
	1		Bricket	28	..	..	28	115	..	52
	3		„	1	21	6	28	110	..	50
98	1	1 lime, 2 C. B. soorkee,	Joint	28	..	..	28	193	10·7	..
	3		„	..	21	7	28	324	18	..
	1		Bricket	28	..	..	28	312	..	142
	3		„	1	21	6	28	219	..	100
132	4	1 lime, 3 C. B. soorkee,	Joint	28	..	..	28	312	17·3	..
	4		„	..	21	7	28	290	16·1	..
	3		Bricket	1	24	3	28	172	..	78
	3		„	1	27	..	28	347	..	158
103	2	1 lime, 4 C. B. soorkee,	Joint	28	..	..	28	117	6·4	..
	3		„	..	21	7	28	89	5	..
	3		Bricket	1	21	6	28	173	..	79

APPENDIX.—(*Continued*).

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets.	Age. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength, lbs. per square inch.	Tensile strength, lbs. per sqr. inch.
SERIES D.—*Mortars of shell-lime and soorkee*—(Continued).										
106	3	1 lime, 6 C. B. soorkee,	Joint	28	..	..	28	60	3·3	..
	2		„	..	21	7	28	58	3·2	..
	3		Bricket	28	..	..	28	163	..	74
	3		„	1	21	6	28	120	..	54
107	3	1 lime, 9 C. B. soorkee,	Joint	28	..	..	28	40	2·4	..
	2		„	..	21	7	28	55	3	..
	3		Bricket	28	..	..	28	90	..	41
	3		„	1	21	6	28	73	..	33
99	1	1 lime, 2 shatty soorkee,	Joint	28	..	..	28	158	8·8	..
	3		„	..	21	7	28	294	16·6	..
	2		Bricket	1	21	6	28	288	..	131
SERIES E.—*Mortars of stone-lime* (*Bangalore*) *and soorkee.*										
134	3	1 lime, 1 S. M. soorkee,	Joint	28	..	..	28	314	17·4	..
	3		„	..	21	7	28	293	16·2	..
	1		„	..	28	..	28	303	16·8	..
	3		Bricket	28	..	..	28	275	..	125
	3		„	1	21	6	28	219	..	99
	1		„	1	27	..	28	252	..	114
135	3	1 lime, 1½ S. M. soorkee,	Joint	28	..	..	28	287	16	..
	3		„	..	21	7	28	336	18·6	..
	1		„	..	28	..	28	282	15·6	..
	2		Bricket	28	..	..	28	275	..	125
	3		„	1	21	6	28	195	..	88
136	3	1 lime, 2 S. M. soorkee,	Joint	28	..	..	28	351	19·5	..
	3		„	..	21	7	28	303	16·8	..
	1		„	..	28	..	28	186	10·3	..
	2		Bricket	28	..	..	28	289	..	131
	3		„	1	21	6	28	216	..	98
	1		„	1	27	..	28	240	..	109
137	3	1 lime, 3 S. M. soorkee,	Joint	28	..	..	28	351	19·5	..
	3		„	..	21	7	28	264	14·6	..
	1		„	..	28	..	28	214	11·9	..
	2		Bricket	28	..	..	28	333	..	151
	3		„	1	21	6	28	175	..	75
	1		„	1	27	..	28	327	..	148

APPENDIX.—*(Continued).*

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets	Age. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength, lbs. per square inch.	Tensile strength, lbs. per sqr. inch.
SERIES E.—*Mortars of stone-lime (Bangalore) and soorkee*—(Continued).										
138	3	1 lime, 4 S. M. soorkee,	Joint	28	..	..	28	213	11·8	..
	3		,,	..	21	7	28	180	10	..
	2		Bricket	28	..	..	28	309	..	140
	3		,,	1	27	..	28	222	..	101
139	2	1 lime, 5 S. M. soorkee,	Joint	28	..	..	28	277	15·4	..
	3		,,	..	21	7	28	133	7·4	..
	2		Bricket	28	..	..	28	265	..	120
	3		,,	1	27	..	28	203	..	92
140	3	1 lime, 7 S. M. soorkee,	Joint	28	..	..	28	90	5	..
	3		,,	..	28	..	28	60	3·3	..
	2		Bricket	28	..	..	28	188	..	85
	3		,,	1	27	..	28	150	..	68
SERIES F.—*Concretes of soorkee mortar and sand.*										
112	2	1 shell-lime. { 3 S. M. soorkee, 3 sand,	Bricket	28	..	..	28	240	..	109
	3		,,	1	21	6	28	281	..	127
113	2	1 shell-lime. { 3 S. M. soorkee, 6 sand,	Joint	28	..	..	28	85	2	..
	3		Bricket	28	..	..	28	158	..	72
	2		,,	2	21	5	28	274	..	124
114	4	1 shell-lime, { 5 S. M. soorkee, 5 sand,	Bricket	28	..	..	28	96	..	43
	3		,,	6	19	5	28	202	..	91
69	1	1 Kolar lime, { 2 S. M. soorkee, 1 sand,	Joint	28	..	..	28	190	10·5	..
	2		,,	..	21	7	28	347	19·2	..
151	3	1 Bangalore lime, { 2 country soorkee, 1 sand (as used in building for concrete mortar).	Bricket	1	27	..	28	245	..	111

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets.	Age. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength, lbs. per square inch.	Tensile strength, lbs. per sqr. inch.
		SERIES G.—*Mortars of shell-lime and limed soorkee.*								
144	3	1 lime soorkee, ..	Joint	28	..	..	28	262	14·5	..
	1	(Soorkee made with blue	„	..	1	..	1	33	1·8	..
	1	clay and 10 per cent.	„	..	3	..	3	144	8	..
	1	of shell-lime).	„	..	7	..	7	282	15·6	..
	3		„	..	28	..	28	561	31·1	..
	3		„	1	21	..	28	373	20·7	..
	3		Bricket	1	27	..	28	229	..	104
	3	Concrete made with 1	Joint	28	..	..	28	262	14·5	..
	1	of the mortar, 1 of	„	1	27	..	28	240	13·3	..
	3	sand, ...	Bricket	28	..	..	28	264	..	120
	3		„	1	27	..	28	285	..	130
145	3	1 lime, 2 soorkee (same	Joint	28	..	..	28	250	13·9	..
	1	as the preceding), ..	„	..	1	..	1	64	3·5	..
	1		„	..	3	..	3	142	7·9	..
	1		„	..	7	..	7	291	16·2	..
	3		„	..	28	..	28	301	16·7	..
	3		„	1	27	..	28	368	20·4	..
	3		Bricket	1	27	..	28	262	..	119
	3	Concrete made with 1	Joint	28	..	..	28	300	16·6	..
	2	of the mortar, 1 of	Bricket	28	..	..	28	346	..	157
	3	sand,	„	1	27	..	28	377	..	171
146	3	1 lime, 3 soorkee (same	Joint	28	..	..	28	326	18·1	..
	1	as the 2 preceding), ..	„	..	1	..	1	50	2·8	..
	1		„	..	3	..	3	210	11·6	..
	1		„	..	7	..	7	297	16·5	..
	3		„	..	28	..	28	296	16·4	..
	3		„	1	27	..	28	297	16·5	..
	3		Bricket	1	27	..	28	268	..	121
	3	Concrete made with 1	„	28	..	..	28	269	..	122
	3	of mortar, 1 of sand,	„	1	27	..	28	348	..	158
147	1	1 lime, 4 soorkee (same	Joint	..	1	..	1	50	2·8	..
	1	as the 3 preceding).	„	..	3	..	3	138	7·6	..
	1		„	..	9	..	9	190	10·5	..
	2		„	..	28	..	28	210	11·6	..
150	1	1 lime, 3 soorkee (soor-	Joint	..	1	..	1	34	1·9	..
	3	kee made with blue clay	„	..	28	..	28	211	11·7	..
	3	and 5 per cent. of shell-	„	1	27	..	28	247	13·7	..
	3	lime).	Bricket	1	27	..	28	173	..	78
	3	Concrete made with 1	„	28	..	..	28	244	..	119
	3	of mortar, 2 of sand.	„	1	27	..	28	255	..	116

APPENDIX—(*Continued*).

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets.	Age. Days in air.	Days in water.	Days drying.	Total ages.	Breaking weight average, lbs.	Adhesive strength, lbs., per square inch.	Tensile strength, lbs. per sq. inch.
		SERIES H.—*Lime and clay cement (twice kilned).*								
43	2	Slaked shell-lime and fine	Joint	28	..	..	28	422	23·4	..
	2	clay (dry) equal parts	„	..	22	6	28	250	13·9	..
	2	by weight, ...	„	3	19	6	28	500	27·5	..
74	1	Slaked shell-lime and fine	Joint	28	..	..	28	84	..	..
	1	clay (dry) equal parts	„	..	21	7	28	188	..	..
	2	by weight. 1 slaked	„	1	21	6	28	105	..	..
		lime, 2 clay, ...								
		SERIES I.—*Portland cement.*								
156	3	Cement, neat, ...	Joint	..	1	..	1	59	3·2	..
26	1		„	..	6	1	7	501	28*	..
	2		„	..	22	6	28	505		
148	7		Bricket	1	6	..	7	399	..	181
	3		„	1	27	..	28	483	..	219
44	6		„	1	21	6	28	502	..	228
116	3		„	1	21	6	28	471	..	214
	3		„	1	79	..	80	666	..	302
149	2	1 cement, 1 sand, ..	Joint	8	..	8	8	278	15·4	..
157	2		„	..	1	..	1	51	2·8	..
	2		„	..	3	..	3	198	11	..
	2		„	..	7	..	7	306	17	..
	6		Bricket	1	7	..	8	334	..	152
	3		„	1	21	6	28	315	..	143
	3		„	1	79	..	80	583	..	265
	1	1 cement, 1½ sand, ..	Joint	28	..	..	28	265	14·7	..
	1		„	½	6	½	7	154	8·5	..
	1		„	½	21	6½	28	385	21·4	..
	2		Bricket	1	21	6	28	272	..	123
	1	1 cement, 2 sand, ..	Joint	28	..	..	28	150	8·3	..
	2		„	..	21	7	28	180	10	..
	1		„	..	28	..	28	147	8·1	..
	1		Bricket	28	..	..	28	248	..	110
	3		„	1	21	6	28	173	..	78
	1		„	1	27	..	28	157	..	71

* Brick broke off outside the joint.

APPENDIX.—(*Continued*).

No.	No. of Trials.	Composition lime measured in paste.	Brick-joints or brickets.	Age. Days in air.	Days in water.	Days drying.	Total age.	Breaking weight, average, lbs.	Adhesive strength, lbs. per square inch.	Tensile strength, lbs. per sqr. inch.
		SERIES I.—*Portland Cement*—(Continued).								
46	2	1 cement, 3 sand, ..	Joint	1	21	6	28	290	16·1	..
	2		Bricket	1	21	6	28	136	..	61
46	1	1 cement, 5 sand, ..	Joint	28	..	..	28	148	8·2	..
	1		„	1	21	6	28	214	11·9	..
	2		Bricket	1	21	6	28	81	..	87
158	..	1 cement, 1 S. M. soorkee, ...	Joint	..	1	..	1	100	5·5	..
			„	..	3	..	3	264	14·6	..
			„	..	7	..	7	372	20·6	..
			Bricket	1	21	6	28	246	..	112
			„	1	79	..	80	426	..	193
44	1	1 cement, 1½ S. M. soorkee, ...	Joint	1	21	6	28	611	33·9	..
	1	1 cement, 2 S. M. soorkee, ...	Joint	28	..	..	28	255	14·1	..
	2		„	..	21	7	28	403	22·4	..
	1		„	..	28	..	28	276	13·3	..
			Bricket	1	21	6	28	245	..	111
			„	1	27	...	28	194	..	88
		SERIES E.—(*Concluded*).								
		Mortars of Bangalore stone-lime and country brick soorkee both unsifted, taken from the trough in which they were being mixed, by hand, for brickwork and concrete.								
152	3	1 lime, quick, entire, 3 soorkee, ...	Joint	28	..	..	28	52	2·9	..
	3		„	1	27	..	28	113	6·2	..
	3		Bricket	1	27	..	28	274	..	124
153	3	1 lime, slaked and beaten free of kuppy 2 months before, 3 soorkee, ..	Bricket	1	27	..	28	269	..	122
154	3	Ditto, kept 16 hours, then beaten up again, ..	Bricket	1	27	..	28	231	..	105

NOTE.—From these last three experiments it is seen that roughness of materials does not injure the quality of concrete as it does that of a mortar for brickwork. The tensile strength is nearly as good as that obtained with carefully prepared lime and soorkee.

Approximate standards of quality for mortar.

	For Masonry.	For Concrete.
	Adhesive strength after 28 days (under water if for hydraulic work), lbs. per sq. in.	Tensile strength after 28 days (at least 21 under water, if for hydraulic work), lbs. per sq. in.
Indifferent, ...	5	50
Good, ...	10	100
Very good, ...	15	150
Excellent, ...	25	200

E. N.

No. CXLVII.

ON AN IMPROVED FORM OF LEVEL.

[*Vide* Plate XIII.]

By Francis J. E. Spring, *L. C. E., Trinity College, Dublin, and Asst. Engr., P. N. (S.) Railway.*

The following paper is a description of a modification of Troughton's Level, which I have made, and which I beg leave to call an improvement, as I shall now endeavour to show.

These adaptations I had no difficulty in making myself (at the Kuthala Workshops, Chenab Bridge, Punjab Northern State Railway).

Referring to *Fig.* 1, it will be seen that my modifications are two. First, the connection of the spirit level with the horizontal plate A by independent supports, without the intervention of the telescope, so that any adjustments of the telescope do not affect the level.

It consists in simply cutting off the screw B and hinge C, *Fig.* 2, and rounding off the tops of the rings in which the telescope rests, and fixing two separate supports DD, *Fig.* 1, (which surround, but are of larger diameter than the telescope,) for the level, to the plate A by means of screws from underneath. This alteration by itself is of little use, but it is essential to the proper working of my second improvement.

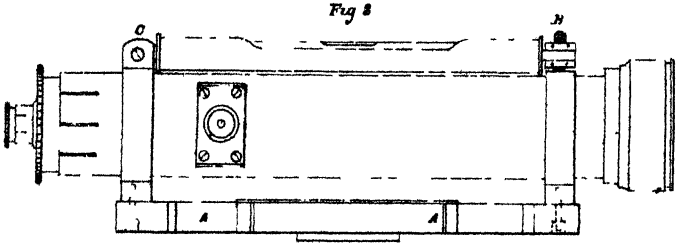
The second, and in my opinion most important, alteration, is my *revolving eye-piece*, (which carries the diaphragm,) of which I shall first endeavour to describe the action, and afterwards the advantages.

The eye-piece end of the inner tube of the telescope having been strengthened by a $\frac{3}{16}$" thick ring of brass, E, being brazed round it, was carefully centred in the lathe, and turned as perfectly as possible on the

LEVEL IMPROVEMENTS.

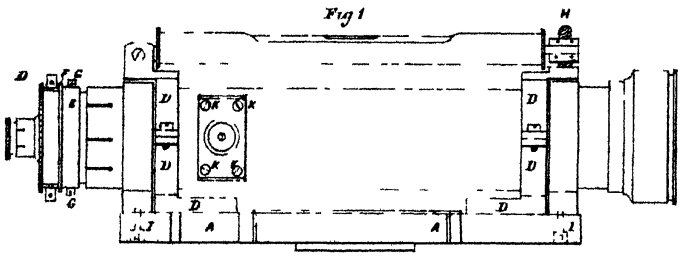
Scale ½

Fig 2



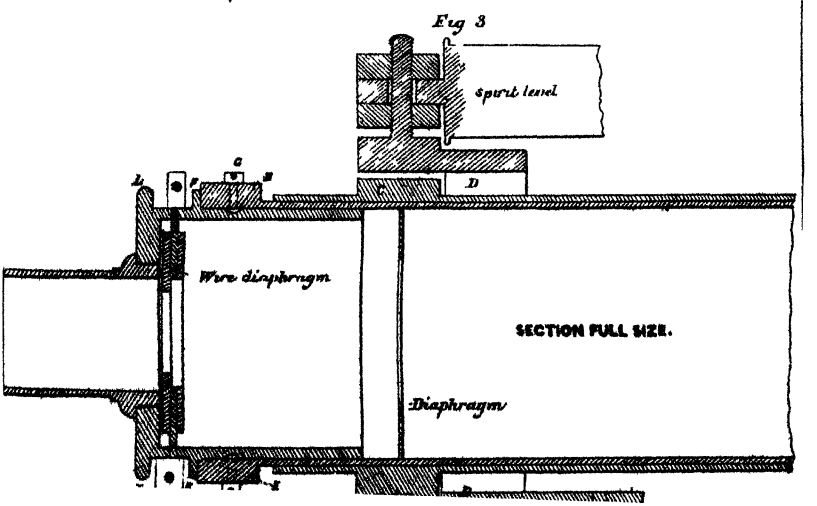
ORIGINAL LEVEL.

Fig 1



IMPROVED LEVEL.

Fig 3



inside, for about an inch, and outside over the ring E and on the end. The new eye-piece is as per *Fig.* 3, longer than the ordinary eye-piece, and is turned so as to fit accurately and revolve freely in the inner telescope tube. It has a flange F, just behind the diaphragm screws, which fits perfectly against the end of the inner telescope tube.

The eye-piece is kept in place, and at the same time permitted to revolve by the points of the screws G, G, which fit in a groove turned round the eye-piece. The upper of these screws can be screwed down into a hole into which it fits when the eye-piece is in its normal position.

All being now arranged as above, and the level being set up in any position, (or to simplify matters, and get all idea of *level* out of the reader's head, let us suppose the *telescope* held in any nearly horizontal position, in a vice or otherwise,) a staff is set up at any convenient distance, say three hundred feet, and read. The eye-piece is now made to revolve half round, and the staff again read.

If the readings be not the same, correct by the diaphragm screws, (as is done when the whole telescope of a Y level is made to revolve in its Y's).

The horizontal wire is now in the centre of the telescope.

Let me now describe the advantages of these alterations. Suppose the instrument to be all out of adjustment as follows:—

(*a.*) The level axis is not at right angles with the cone axis, in other words the bubble does not *reverse*.

(*b.*) The horizontal wire is not in the axis of the telescope.

(*c.*) The axis of the telescope is inclined, and not perpendicular to the cone axis.

To Adjust.

1*st.*—Adjust the spirit level in the ordinary way so as to reverse, (*i. e.*, half with the foot screws and half with the screw H.)

2*nd.*—Set up a staff at say 300 feet off, and adjust for parallax and read. Half revolve my eye-piece round its own axis, and again read. Correct by the diaphragm screws so as to read half the sum of the former readings. A couple of trials will get the wire so that the readings in both positions are the same.

The horizontal wire is now in the centre of the telescope.

3*rd.*—To get the axis of the telescope parallel to the level axis (the wires having been by adjustment No. 2 got into the centre of the telescope).

When the instrument is set up, and the bubble adjusted so as to reverse, the level axis is a true level line. If, therefore, we have two pegs, the tops of which are known to be of the same reduced level, and while the bubble rests in the centre of its run, so adjust the telescope by means of the telescope screws I, I, that the readings of one staff resting in turns on the tops of two such pegs are the same, we have gained our end. Therefore drive in two pegs, at say 300 feet apart, and having set up the instrument midway between them, and by means of the footscrews brought the bubble to remain in the centre of its run in all position, take readings on both pegs by means of the same staff. Then tap down the higher of these two pegs till the readings on both are the same. These two pegs are now a true level line. Next bring the instrument as near one of the pegs as will admit of distinct vision, and read one staff placed on both pegs in turns; and as the virtual line of sight is not parallel to the level axis, the readings will differ, when the bubble is in the centre of its run. By means of the telescope screws I, I, correct on the farther staff, so as to read the same on both pegs when the bubble is in the centre of its run.

The axis of the telescope, in which the horizontal wire was brought by adjustment No. 2, is now parallel to the level axis.

On the first occasion of the adaptation of this eye-piece to any level, it will be probably found that both supports of the telescope are not bearing hard down on the plate A after adjustment No. 3. In this case it is (as will afterwards be seen) most desirable to so file and fit the bearings, that after adjustment No. 3, they may both bear hard and tight down on plate A. This adjustment will now be permanent, and not likely to get out of order. (Indeed many levels, those of Cook of York, and some new ones of Troughton I believe, are sold with the telescope axis in permanent rectangularity with the cone axis). This being done, all the adjustments required will be *two*, viz., the bubble, and that made by revolving my eye-piece.

With a level fitted as I have described, and as I have fitted mine, any Engineer may do all his adjustments indoors, on a wet day.

My original idea was to make the pinion, which works the telescope rack, removable by substituting more substantial screws for the four little existing ones K, which wear out if often handled: and thus to revolve the whole inner tube in the outer; but the telescope tubes could be with difficulty kept truly concentric along their whole length so as to revolve freely and without shake.

A portion of the inner telescope tube equal to the interval between the forward faces of the flanges F, L, must be cut off before the strengthening ring, E, is brazed on, and a part of the outer tube must be cut off equal to this length, plus the width of this strengthening ring.

The *permanent* adjustment of the axis of the telescope into rectangularity with the cone axis is best performed by the instrument maker, or by the amateur mechanic, as follows:—

Temporarily remove the spirit level and its supports.

Bring the horizontal wire into the axis of the telescope by means of my revolving eye-piece.

Set up the level in any nearly horizontal position. (By preference, not on its legs, but by firmly clamping the footscrew plate to a strong bench or in a heavy vice, or in the case of a three-screw level, by means of the footscrews screwed down into three holes in the bench). Remove the telescope screws I, I, and place the telescope on the plate A in its usual position, and read a staff set up on a peg about 300 feet off. Now lift up the telescope, and revolve the plate A (and with it of course the cone) half a revolution round the cone axis. Again place the telescope on the plate A, looking towards the staff as before, (but with its ends reversed, of course, with respect to its former position on the plate A,) and read. Correct, so as to read half the sum of this and the former reading, by filing and fitting the underneath surface of one or both the telescope supports. A few trials will make the readings, in both positions of the plate A, identical.

Now insert the screws I, I, and, having brought the telescope supports to bear hard down on the plate A, the axis of the telescope will be in permanent adjustment, (bar accidents and falls which may bend the plate A).

As the description of *this* method of permanently adjusting the telescope axis has been inserted only for the benefit of instrument makers and such Engineers as are also practical fitters, I have not thought it necessary to go into very minute details as to the *reason why*.

In conclusion, I wish it to be clearly understood that the getting of the wire into the axis of the telescope is not the principal object of my new eye-piece, for this position of the wires has been proved by Professor Blood to be not essential to accurate levelling.

My object is the more easy adjustment of the visual line, parallel to the level axis, the axis of the telescope having been first, by repeated trials

and fitting and filing, placed in permanent adjustment, *i. e.*, at right angles with the vertical axis (or parallel with the level axis). This object has I hope been now gained, and with a level so fitted up, the Engineer, who frequently while on extensive surveys finds difficulty in sparing a morning for testing his level adjustments, will be able to use for this purpose many a wet or unfavorable day which otherwise would have been a *dies non.*

I may mention, that I have converted the Level, to which I adapted the above improvements, from a four screw to a three screw Level by re-removing the lower parallel plate and ball and socket, and enlarging the upper parallel plate to a triangular form. The advantages of a three over a four screw instrument, are I think appreciated by all Engineers who have tried both.

January 6th, 1875. F. J. E. S.

No. CXLVIII.

SHORT ACCOUNT OF A TRIANGULATION MADE ON THE HOLKAR STATE RAILWAY IN 1870-71.

By Lieut. W. H. Johnstone, R.E., *Asst. Engr., Ghât Division, Holkar (State) Railway.*

It is not often that an engineer is called upon to make an independent triangulation for the basis of a survey; but since it may sometimes happen that no maps or surveys of the country exist suitable for the purpose, it is hoped that the following may be useful.

The location of the Holkar State Railway, as it ascends to the Malwa plateau through the Ghâts of the Vindyas, was a point of some difficulty. Several alternatives offered themselves, and although the Superintending Engineer (Mr. Crawford Campbell) at once selected the line which was eventually adopted, the Government of India, in a matter of such importance, determined to have every possible line run, and a survey made to connect the whole.

Twenty-one trial lines in all were run, and as no survey of the country existed at the time, it was necessary to have some basis, either of triangulation, or of traverses, with which the different lines of levels could be connected.

The whole of the surveys, including the numerous trial lines, were under the direction of Mr. Stanley Alexander, who entrusted to the present writer, the task of triangulating the Choral Valley. The field was taken on the 24th November, 1870, the survey party moving into camp near the village of Chorlia, about five miles from Mhow.

The first operation was to measure a base; and it was with great difficulty, that a tolerably level site, fit for the purpose, could be obtained.

On the 28th November, and two following days, a base line was ranged out, and measured with levelling staves, under Mr. Alexander's own supervision.

The length of the measured base was 4105·77 feet, but this was produced by triangulation to 9932·28 feet.

The azimuth also of the base was determined by a greatest elongation of the Pole Star, and the variation of the compass found to be 2° 3′ 45″, East.

On the 4th December Mr. Alexander broke up his camp, and went to superintend the running of the trial lines; and the writer was left with four native plane-tablers, who were to sketch the country on their plane tables, as the trigonometrical points were given to them.

Before describing the methods of observing and calculating, which were adopted, it will be as well to explain the general character of the Survey, and to point out some of the difficulties which were peculiar to it.

The triangulation made, was about seventeen miles long, and embraced the Choral Valley and the hills on each side, varying in width from three-quarters of a mile to three miles, and even more as the valley widened out at the lower end. The system of triangulation adopted was "Quadrilateral," as this best admits of checking in the manner to be presently described, and the country generally was favorable to this form.

The height of the hills on each side above the river Choral, may be from 500 to 1,500 feet. These hills are covered with trees and brushwood, and in nearly every instance rays had to be cut from each point to the surrounding stations.

The "stations" consisted of stout "bullies," projecting three feet out of the ground, and surmounted by "chatties." Both were whitewashed, and when it was necessary to observe from any station, the chattie was removed, and the theodolite centered over the bullie.

The theodolites were six-inch "Everest's", reading with three verniers to 30 seconds.

The whole of the surveys were plotted to a scale of 300 feet to the inch, which necessitated some care in the triangulation, if it was to be of any use.

The peculiar difficulties were principally the small size and untrustworthy nature of the instruments, which had already seen many years

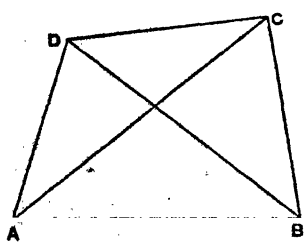
service in the D. P. W.; and secondly, want of time. Indeed it may truly be said, that the whole of this season's work, from first to last, was a race against time.

The method of observing was to take two rounds of angles at each station, one from zero 360°, and the other from zero 180°. Thus having read all the three verniers, six values for each angle were obtained.

These were *weighted* by estimation according to the remarks in the Field-book, or where no remarks were recorded, the mean of the six angles was taken. The three angles of a triangle thus found, should of course amount to 180°, but in practice, there is always a small excess or defect, which is called the "triangular error," and which in the present instance, as a preliminary measure, was equally distributed over the three angles.

The triangular error of these triangles was large, as might have been expected, amounting sometimes to as much as 30 seconds; and the following tentative method was adopted to reduce it.

Let ABCD be a quadrilateral of the series, of which the side AB has been previously determined. Then, all the angles having been observed, the triangles ADB and ABC can be solved from AB. Thus AC and BD become known; from which the triangles BDC and ADC are solved, and so two values are obtained for DC. If these agreed within a few inches, the next quadrilateral was proceeded with in the same manner. If however, the values of DC thus found, did not agree satisfactorily, the triangular errors of the four triangles of the quadrilateral, were re-distributed according to reasoning such as the following:—



Suppose the value of DC found from the triangle BDC was larger than that found from ADC.

Then in the one case:—

$$DC = \frac{DB \cdot \sin DBC}{\sin DCB}$$ which is too large, and in the other

$$DC = \frac{AC \cdot \sin DAC}{\sin ADC}$$ which is too small.

Note.—I was not at this time acquainted with the method of "least squares," but have since applied it, out of curiosity, to some of the triangles, and find that it reduces a triangular error of 27 seconds to a *probable* error of about 17 seconds.

Of course these triangles are far too small to make "spherical excess" appreciable.

Hence the angles DCB, DAC, and the side AC, must be increased, and the angles ADC, DBC, and the side DB diminished.

Also to increase the side AC, the angle ABC must be increased, and to decrease the side DB, the angle BAD must be diminished, and so on.

It generally required several trials to secure a satisfactory result, each trial of course involving the solution anew of four triangles.

The labour of such a process can only be imagined, by remembering the fact, that selecting stations, clearing rays, observing, calculating and plane-tabling, all went on simultaneously.

On the whole, there were very few hitches when once a start was made, and the last triangle of the series was plotted on a plane table, on the 4th March, 1871. At a distance of 10 miles from the base line, a "base of verification" was measured, but it was impossible to obtain a greater length than about 600 yards, owing to the rugged nature of the country. The measured length was 1871·8 feet, and the calculated value differed from it by only $\frac{1}{10}$th of a foot, or rather more than an inch.

This is equivalent to an error of about $3\frac{1}{3}$ inches to the mile, but all things considered, this can only be looked upon as a lucky coincidence.

The triangulation, however, proved itself to be abundantly accurate for the purpose for which it was intended, viz., for tying together all the trial lines and isolated surveys and traverses, which were made.

A triangulation like the above, must not be compared to the field work done by a regular survey staff, fully equipped and organised. The conditions are altogether different, nor are the purposes, for which they are intended, at all the same.

The short account here given, is simply "an experience," a little outside the ordinary practice of a railway engineer; but which may occur again in countries yet unsurveyed, or even in parts of India.

W. J. J.

No. CXLIX.

LEAVES FROM A SUPERINTENDING ENGINEER'S NOTE BOOK.

[*Vide* Plates XIV. and XV.]

By Lieut.-Col. J. G. Medley, R.E., *Assoc. Inst. C.E., Supdg. Engineer, Punjab.*

Concrete.—We are using concrete in this circle for the walls of small buildings, with great advantage in point of economy. It is generally a good deal cheaper than kucha-pucka brickwork or stone in lime (pucka rubble), being executed at from Rs. 10 to 14 per 100 cubic feet.

The best proportion for foundations at Rawal Pindee has been found to be 18 parts (by measure) of slaked (stone) lime, 35 parts of bujree or gravel (washed), 30 parts of soorkee, 100 parts of stone broken to 1¼-inch gauge. The lime and soorkee are mixed in a regular mortar-mill, the bujree is then added, and finally the stone. The mortar is mixed one day and put into pucka tanks; the next day it is taken out to be mixed with the other material, and put into site by 11 A. M., and then rammed up to 6 P. M.: nothing is put down after 11 A. M. This is the concrete used in the new Fort works.

For superstructure, it is better to dispense with the stone altogether, and to use only bujree. In the new Female Ward, lately built at the Rawal Pindee Jail, the walls, 16 feet high and 2 feet thick, have been built entirely of concrete, composed of 12 cubic feet of lime, 20 cubic feet of soorkee, and 100 cubic feet of bujree. The concrete was carried up between boards in 6-inch layers and rammed, and the work was done for Rs. 15

per 100 cubic feet. The flat arches over the doors and the verandah pillars have been executed in the same material.

A box of known capacity being filled with as much of the broken stone as it will hold, water is then poured in until the box is full. The quantity of water so poured in will of course show the amount of *mortar* that will be required to fill up the interstices in that quantity of stone.

In order to determine the *cheapest* quality of concrete that it is safe to use,—as it is very difficult to test the actual resistance to crushing—it seems sufficient to determine the minimum tensile strength that may be allowed for the mortar—say 20 lbs. per square inch—and then to add bujree to fill up the interstices.

At Kohát, a block of concrete 9 × 9 × 18 inches between points of support, composed of 1 part lime, 1 part soorkee, 2 parts sand, (equivalent to 3 cubic feet of mortar,) and 7½ cubic feet of ballast, after setting one week, broke transversely with 180 lbs. at the centre; after one month, with 234 lbs.; and after three months, with 418 lbs.; the mortar itself breaking in tension with 14 lbs. per square inch. Such a concrete, therefore, would not be safe for any but low buildings.

Iron Cement.—There is a cement used at Kalabagh, on the Indus, which I have not seen described in books. It is composed of 2 parts of pounded iron slag, or refuse from a common native furnace, to 1 part of clay, simply mixed together with water. It sets rapidly, and is very strong. Though too expensive for general adoption, it would be excellent for filling up cracks, or perhaps for paving the floors of racket courts, &c.

Sind tiles.—The hollow hexagonal tiles, described in the Roorkee Treatise, have been lately introduced into this circle for roofs with economy and advantage, timber being very dear. The tiles we have found best adapted for use have sides of 4 inches at one end, and are 8 inches long; the sides of the lower end being ¼-inch shorter, so that the tile has a voussoir shape; otherwise there is leakage through the joints. We have found no difficulty in making them from the description in the books, but Captain Armstrong, at Kohát, has invented an improved mould and screw press, which turns out the tiles in a very superior and more economical manner.

Cost of Bridges.—From a large number of bridges which have been constructed in the circle, of brick and stone, with arches or timber superstructure, it appears that Rs. 2-8 to 3 per foot (superficial) of roadway

(between the parapets and from end to end of the bridge), may be taken an approximate estimate for bridging a stream when there is no extraordinary difficulty with the foundations.

Cost of Buildings.—From a large number of buildings erected in this circle, it appears that the cost per foot, (cubic,) of actual accommodation provided, (without verandahs,) varies from 2 annas to 5 annas according to the style of construction.

Road Metalling.—The following kinds are used in this circle:—

I. *Shingle or bujree* from the beds of nullahs, laid down in 2-inch layers, not rolled or rammed, consolidates well and quickly under wheel traffic, and where available, makes an excellent and economical metalling.

II. *Sandstone* broken to 1 inch gauge, and laid (in 2-inch layers), loose as in England—consolidates quickly under wheel traffic, and makes a very good metalling, but will not stand very heavy traffic. Both these kinds have lately been used on the Rawal Pindee and Murree road, and answer well.

III. *Limestone*, blue and white: the stone is broken to 2-inch gauge, laid down 4½ inches thick, and rolled dry with a heavy roller, then covered with ¾-inch of dry earth; this is picked in, watered, and then rolled again, and finally covered by a ½-inch layer of stone siftings, (made by screening the stone at the road side,) which is again watered and rolled. These siftings are ground to powder by the traffic, and then fall into the interstices below, and help to bind the stone together. This is used on the greater portion of the road from Jhelum to Peshawar, and is the very best kind of metalling possible.

IV. *Broken flint boulders* are also used in a similar manner, but make a very lumpy metalling, which it seems impossible to consolidate properly.

The following figures may be useful:—

Jhelum and Rawal Pindee road, length 67 miles, average cost of carriage, stacking and breaking metal, ...	Rs.	7	8	0	per 100 cubic feet.
Do. do., consolidating, ...	„	1	10	0	„
Total, ...	„	9	2	0	„

1 mile long, 12 feet wide, 9 inches thick, costs Rs. 4,334 to make, and about Rs. 700 annually to keep in repair; and capitalizing this last

at 5 per cent., 1 mile of metalling represents a sum of Rs. 18,334. A layer of this metal 4½ inches thick, ought to last five years with occasional petty repairs, if properly laid at first.

Kucha Roads.—Except the Grand Trunk Road, all the roads in this circle are kucha, and are very difficult to keep in proper repair from the quantity of drainage crossed. The large nullahs are not bridged, but have sloped approaches to them; these should be made 1 foot in 15 feet. The hill roads, of which there are many miles, are generally drained towards the inside, but occasionally to the outside, and the latter mode has some advantages where a road cannot be constantly looked after.

The protective parapets for these hill roads are made of wood or stone. On the higher parts of the road, the wooden railings are often carried away by avalanches of snow, and stone walling is both cheaper and more durable. The best and cheapest mode is to employ very large blocks of dry stone, too heavy to be thrown down the khud by any mischievous person, and which, if there is any cart traffic, are as effectual a protection to the traffic, as a wall of solid pucka masonry.

Bridges.—Bridges on these roads are of all sizes and kinds. Concrete barrel bridges have been lately made, and answer well in point of economy. The best timber bridges we have, are those over the Leh and Salgram nullahs; the latter has just been put up on the Murree road, to replace the old one which figures in the Roorkee Manual on Bridges, and which was erected 16 years ago by Captain Glover: being of *cheer* wood not properly seasoned, it could not be expected to last longer. The new bridge has three girders with oblique struts of deodar, and vertical iron ties, with cross struts only at the middle portion of the bridge. These trusses are very strong and stiff; and, when well made, the joints do not seem to work loose at the hardwood abutting blocks, which are the weak points of this kind of bridge.

The bridge now being erected for the Rawal Pindee Municipality over the Leh nullah, is of similar construction, and has three openings of 61 feet span, each span composed of three ribs. The girders are continuous throughout—the roadway is on the top. The piers are of stone with well foundations.

In Hazara we always use the strut and strain bridge; as, with iron tie bridges, the nuts, &c., are very apt to be stolen.

On the frontier roads, the people often steal the wood from the tempo-

rary bridges; in those lately made, I have had the beams built into the masonry, and the planks strongly clamped down.

The Zemindars are very fond of making irrigation cuts or raised channels right across the roads. This of course should be prohibited or punished, and a sufficient number of permanent channels provided. In the Peshâwar District, we have lately made these of 9-inch earthenware drainage tiles, surrounded by concrete, costing only Rs. 10.

On all the boat bridges, the old native boats and superstructure are being replaced by Colonel Taylor's new pattern for both—of which a description will be found in the Roorkee Treatise. The annual cost and short wear of native *moonj* rope is so great on these bridges, that we propose in future to use English rope for all the portions, except the cables, which are often lost in dismantling the bridge.

River Spurs.—Many of the streams and torrents in this circle require training, to keep them straight for the bridges, and prevent the destruction of their banks. For the latter purpose, we have found the old plan of cutting back the banks to a gentle slope, and planting willow cuttings or tufts of grass, answer well. Earthen spurs revetted with fascines, were tried last year in a very troublesome torrent—instead of masonry spurs, and were very successful.

The following account of a still more economical kind of spur or groin, which has lately been tried with success, may be interesting to many:—

The Deena nullah crosses the Lahore and Peshâwar road about 12 miles above Jhelum, and is spanned by a masonry bridge of 10 arches of 40 feet span. About 500 yards above the bridge, the nullah makes a sharp bend to the right, and the action of the stream at this bend has for some years past been severe, threatening to force a new channel for the water, which might eventually desert the bridge altogether. Masonry spurs and walls were built at the spots shown in the plan, *Plate* XIV., and lines of trees tied to chains were found useful in defending the banks below the bend. Two years ago, however, a heavy flood cut into the bend, forced its way behind the wall A, which it breached in the middle, scouring out a deep hole at the breach.

The bed of the nullah is composed of pure sand, the banks being also very friable. It has a fall of 11 feet in the mile, and though the floods are not of long duration, they are very violent while they last, varying in depth from 8 to 9 feet.

In order to prevent further action at the bend, and to turn the stream down towards the bridge, it was resolved to try the effect of *Sand* spurs, revetted with fascines, dispensing altogether with *stone*, (which would have had to be brought from a long distance,) and with *piling* (which would have been very expensive), the principle sought to be established being, that *by presenting to the water a long, flat slope, up which it should have to climb, instead of a vertical face, the scour would be reduced to a minimum.*

The spurs were build at the spots shown in the plan, *Plate* XIV., and were made of pure sand, taken out of the bed—the up-stream faces and the ends or noses of the spurs were laid out at a slope of 10 to 1, and protected by fascines made from the long grass growing on the nullah banks. They were finished in April last, and have since stood several severe floods, effectually diverting the water, and preventing any action in the bend, while large deposits of silt have been made between them. The scour at the foot of the upper spur, which of course had to bear the brunt of the water's action has been very slight. Even had it been greater, the spur would simply have sunk, and the fascines would have protected it from being washed away.

The experiment was certainly a risky one, in a stream of so great a fall to its bed, and with a full flood of perhaps 24 hours duration, the spur would probably not have stood. But in sandy nullahs of less slope, and even in large rivers with a moderate current, it is believed that these spurs will be found economical and efficient—chiefly in saving a recourse to piling, which is always so expensive. After the first year, the spur may probably be found to be a distorted and shapeless mass, but so long as it stands without being breached or carried away, a heavy deposit of silt will certainly take place above and below it, and if grass be planted on it, the second year will probably find it impervious to the attack of further floods.

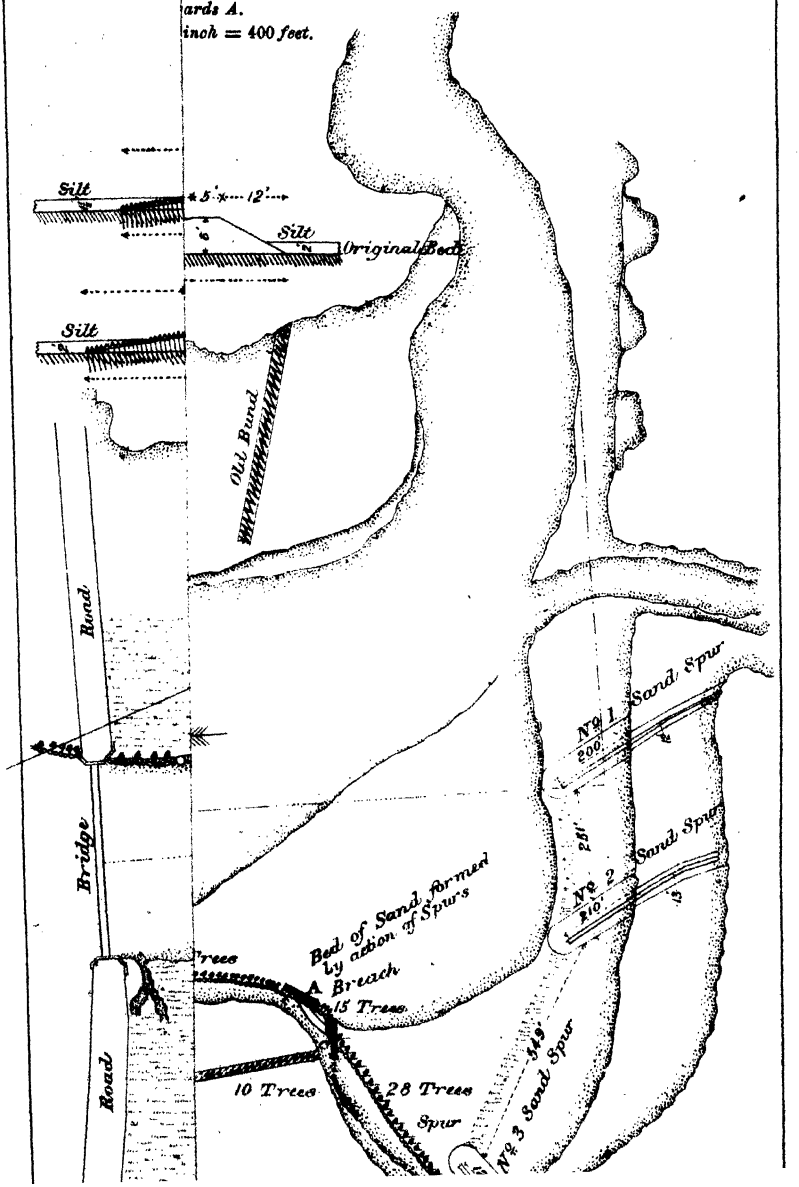
It must be remembered that the whole principle of the thing, (if there *be* a principle,) depends on the length and flatness of the up-stream slope, which should not be less than 10 to 1, and the sole limit to which is the consideration of expense. Also that the greater the velocity and duration of the stream, the flatter evidently should be the slope. On the down-stream side, of course a much less slope will suffice.

It is believed that a similar plan might be pursued in constructing river levees or embankments, which, in important* cases, should be made *double*, the two being separated by an interval of perhaps 100 yards, and connect-

* As in the Railway embankments at the Sutlej Bridge, for example.

LAH,

the floods of 1874.
ards A.
inch = 400 feet.



ed at intervals by cross bunds. The advantage of this method would clearly be the isolation of any breach in the first embankment; and by gently admitting the water through temporary sluices into the interval, there would probably be so large a deposit of silt, that the whole space would virtually become one massive bank.

For the protection of the slope, instead of fascines of coarse grass or brushwood, which have here been used, thick ropes of grass regularly pegged down, or wicker hurdles interlaced with grass, might be employed if found cheaper. Sand bags have been employed on the Chenab River works, but will generally be found more expensive.

In more violent streams where stone is available, it is believed that the adoption of the same principle, though to another material, will often effect a considerable saving. Thus, in lieu of erecting spurs of solid pucka masonry with deep foundations, as is generally the case, spurs of loose stone, with a long slope towards the water would be cheaper, and probably as efficient—with the additional advantage over a solid spur, that in case of scour, the loose stones would fall down and fill up the hollow, while the solid spur would crack and fall to pieces. In this case, the only caution necessary would be to face the slope with very large stones, too heavy to be moved by the action of the water. If these could not be procured, it might be necessary to employ crib work, or to set the outer layer only in mortar.

Metalled Gaps.—On some parts of the Lahore and Peshâwar Road, many drainage lines are crossed that only bring down water for perhaps a few hours during the year. To save the cost of bridging them, metalled gaps have been left, defended by apron walls on both sides. The action of a flood on the down-stream side is often very severe, causing a considerable scour to the depth of 4 or 5 feet. The best mode of protection has been found to be, to form a rapid (at a slope of 10 to 1) of dry boulders below the apron wall, the largest stones being reserved for the upper layer.

Some of these nullahs have a small perennial stream, over which a bridge is thrown, the spring of the arches being on the same level as the floor of the gap, so that when the nullah is in flood, the whole gap is covered with water, without silting or blowing up the arches.

Two Sub-merged Bridges of this kind have been built on the G. T. Road near Attock, and on the Kohât and Hungoo Road.

On the Kohât and Attock road, a nullah is crossed by a weir pierced

with small arches, through which a small flood finds its way, while a large flood will pour right over the weir. As soon as the flood is over, the communication is restored.

Such a weir is sometimes made without arches, and is useful not only to carry the road across, but also to pond up a supply of water after a flood, which in the dry, rainless, tracts of the Northern Punjab, is of great value to the people and their cattle.

Water Supply.—The water supply of many towns in the Northern Punjab is in a very unsatisfactory state. For Peshâwar, a scheme is now in progress for leading water from the Bara river, six miles off, through concrete ducts and iron pipes.

In Rawal Pindee, the unhealthiness of the city is chiefly attributed to the unsatisfactory state of the water supply. The wells are 100 feet deep, and often dry up, just before the rains—the people use the water of the Leh nullah, which, as it is also used for bathing and clothes washing, is fearfully polluted. A scheme is now under consideration for bringing in a supply from the Rawal pool, nine miles distant.

In Kohât, the Government has gone to considerable expense in bringing in a stream for the Cantonments, from a spring near the fort. This is led through closed channels of concrete, into several covered masonry tanks, from which it is drawn by brass taps or cocks, to which descent is effected by a flight of steps from the ground level. In each tank, one tap is set apart for the use of Hindoos.

At Haripur, in Hazara, a similar tank has been made in the centre of the bazar, with the addition of a filtering chamber through which the water, which is excessively foul, is first passed through four feet of crushed quartz. The water is thoroughly purified to taste, smell and sight, and is freely used by the people.

A drawing of this tank is given on *Plate* XV., and the following is a detailed description extracted from reports furnished by Captain E. T. Wynne, R.E., Executive Engineer.

REPORT.

For the site of such a tank, it is advisable that there should be a means of draining* the area in front of the service cocks; this involves a fall of about six feet below the level at which the water to be filtered is delivered. At Haripur, such a site is easily attainable, as there are several falls in the irrigation channels, at which native mills are placed: the duct to admit the water into the filter being close to the surface and easily accessible: its length does not much matter.

* The drainage water might be pumped up or baled out.—J. G. M.

		Rs.
c. ft.	Brought forward, ...	276
16½	Woodwork, at Rs. 1-8-0 per cubic foot, ...	25
88	Roof covering, at Rs. 5 per 100, ...	4
Seers.		
24	Iron, at Rs. 0-8-0 per seer, ...	12
No.		
2	Brass cocks, &c., at Rs. 26 each, ...	52
c. ft.		
70	Sand for filter, Rs. 0-8-0 per cubic foot, ...	35
60	Broken stone, at Rs. 0-1-6 per cubic foot, ...	6
No.		
1	Padlock, at Rs. 2, ...	2
	Total, ...	412
	Add contingencies, at Rs. 5 per cent., ...	21
	Grand Total Rupees, ...	433

Brickwork.—A large number of the buildings in this circle are of kucha brick masonry in the superstructure. In all but the very commonest buildings, however, three layers of pucka brick masonry are laid under the wall-plates, and the door and window frames are also set in pucka. In many cases it has been found necessary to protect the outer walls of such buildings by a layer of pucka masonry, on the sides most exposed to rain-storms. In general, the kucha walls are only protected by the ordinary kucha plastering.

Roofs.—In roofing, we employ deodar for all buildings of any consequence. Its great and increasing cost, however, has led us to use the Palundar (*Pinus excelsa*) and Byar (*Abies smithiana*), for many buildings in the Hazara district, which if protected from the weather, answer well. In the Kohát district, we use round *bullies*, which appear to be young fir trees, and which are brought in by the frontier people from the hills, and are sold by the score; also *choufalls*, or roughly squared small timbers, of a similar kind.

The roof coverings are various—kurrees and planking, or flat tiles with three inches of pucka terracing, and six inches of earth; mats or brushwood covered with earth, and leped with cowdung. In the Hazara District, shingle roofs are general.

Slab slate of good quality is plentiful at Nowshera and in Hazara, and is often used for flooring, but all attempts to discover a good roofing slate have hitherto failed.

Labor and Establishments.—For the superintendence of work, we principally employ native Sub-overseers, and it is exceedingly difficult to get satisfactory men, especially for these wild, frontier districts. In Kohát and Bunnoo, it is necessary that they should speak Pushtoo, or they cannot make themselves understood. In the cold weather, gangs of workmen come down from the hills, and are employed in road mending, and other work not requiring skilled labor; they are often "rough customers," and require a good deal of management to get fair work out of them. The country is very wild and desolate, villages few and far between, and water very scarce, so that the ordinary Sub-overseer from Hindoostan or the lower Punjab, has not a happy time of it on the whole.

The Executive Engineers of this circle have all very large divisions to look after; the work is much scattered, and riding the only means of locomotion, except on the Grand Trunk Road. Besides the provincial works, they assist the District officers more or less in the execution of Local and Municipal works. The exact relations of the two are not very clearly defined, nor is it advisable that they should be so, as the D. P. Works establishments would require to be very greatly increased to enable them to undertake all the public works in the province; practically, their assistance is sought and given in all cases requiring professional skill, and the arrangement works smoothly enough on the whole.

J. G. M.

No. CL.

LIGHT DRAUGHT BOATS FOR PUNJAB RIVERS.

NOTE.

THE following description has just been received from America of a peculiar class of steamers used in the United States for the navigation of very shallow rivers: it has been obtained through the kindness of Major-General Newton, U. S. Engineers, in view of urging the employment of a similar class of boats for the rivers of the Punjab.

The Sutlej, Chenab and Jhelum, with their tortuous and shifting channels, do not present greater difficulties to navigation than the Missouri, Ohio and Upper Mississippi; and if various attempts have failed in navigating the former, I venture to think it is because we have never yet tried steamers of a proper class; having gone to Europe, instead of America, for our models.

I much regret that General Newton has not been able to procure drawings, for the reasons stated in Major Suter's description. Should they be received hereafter, they can be published in a future number of the Professional Papers.

J. G. MEDLEY,
LIEUT.-COL., R.E.

Extract of letter from Major C. R. Suter, U. S. Engineers, to General John Newton, U. S. Engineers.

I have endeavoured, without success, to obtain what I suppose Col. Medley would prefer, viz., complete plans of a boat of good performance.

In fact, no plans are ever made either of the boat or machinery—rule of thumb being still the favorite method among western mechanics.

The best I can do, therefore, is to give you a general description, which I hope may be intelligible.

As I understand it, you wish for information only about the small, light draught boats used in the navigation of the shallower streams, and which are intended more for freight than for carrying passengers.

We have two general classes of boats, viz., side-wheel and stern-wheel. The former are rather more stylish, and have some substantial points in their favor, notable among which is the facility of handling afforded by their separate and distinct paddle wheels, each of which is driven by a separate engine.

They are, however, more expensive to run, requiring four engineers instead of two, and are heavier for the same carrying capacity. They are also necessarily wider. For these reasons they are rapidly going out of use on the small streams, and even on the large rivers their supersession seems inevitable.

On stern-wheel boats, they always work two engines also, but they are coupled to the main shaft at right angles, and can be handled by one man.

Their action on the wheel, and the whole propelling effect seems to be considerably better than when the same engines and boilers are put on a side-wheel boat of the same size.

Within the last few years, some of those boats have been fitted with compound engines with good results, although the designs which I have seen are rather crude and roughly got up.

I think that eventually they will be very generally used, as the high steam pressures used will give every possible opportunity for their favourable performance.

As far as regards the construction of the hulls, there is but little difference between the two classes of boats—the stern-wheelers are broader in proportion to length, and end with a scow stern. This latter condition is rendered necessary by the fact, that the whole bulk of the machinery, except the boilers, is placed on the stern of the boat, which requires in consequence as large a displacement as possible to carry this weight safely. The bow is more or less modelled according to taste and draught of water, and a large straight body fills up the intermediate space. The sides are generally vertical. The rake of stern must be as easy as possible, other-

wise the eddies produced will spoil the steering, and the wheel will clog up with water in backing, which on these craft is a very important matter. For the same reason the paddle wheel must be set as far aft as possible—running the paddle beams back as far as may be to keep the wheel away from the stern bulkhead.

On stern-wheel boats, built for freight purposes and for light draught, from 130 to 180 feet would be the usual proportions of length. Where model is desired, *i. e.*, speed, or more room is available, the length may run up to 200 feet.

The beam is generally about one-fifth of the length for freighters, although on tow-boats it is often carried as low as one-eighth.

Height at side is generally from one-fifth to one-sixth the beam.

A good deal of shear is given forward—aft it depends a good deal on the size of the wheel.

The hull, which is of course very limber, is kept in shape by a system of chains and braces which distribute the weights of the heavy portions, machinery, &c., to those parts which are more lightly loaded. The distribution of cargo does the rest. They have also a bulkhead, generally solid, which extends from end to end of the boat. In framing and planking, the bow is made the heaviest on account of snags, sand-bars, &c., and the shocks of landing head on. The thickness of plank diminishes up the sides and towards the stern, and also the siding or spacing of the frames—frequently both. Oak is almost always used for frames and bottom, and side planking—deck of pine.

The size and spacing of frames, as well as the thickness of planking, and the amount and number of inside fastenings, depends entirely on the character of boat required. If owners intend to insure, however, they have to conform to the requirements of the underwriter's inspectors. Their rules however are quite arbitrary, and vary with character of the stream for which the boat is built.

The amount of freight to be carried, and the allowable size of boat being given, however, it is merely a question of calculation of allowable weights for the hull and machinery.

The absolute size of frames used varies from about 4 × 6 inches to 2 × 4 inches, and the spacing is from 12 to 24 inches between centres, the wide spacing being for the light frames.

The bottom being flat, the floor is got out in one piece in the straight

body, and also the deck beam. The two side timbers are joined to the floor by a triangular futtock. Where the modelled frames come in, they are got out in as few pieces as possible, the joints being strengthened by half floors and futtocks.

Both deck, bottom, and sides are stiffened and tied by keelsons and clamps, which are bolted through frames and planking. One keelson runs through the centre, and forms the foundation of the bulkhead: another on each side ties in the angle of the floor and side timber. The clamps (one or two strakes) lie against the side timbers under the deck beams. Between these, so called binding strakes run along the floors and side timbers. They are usually about four feet apart. The outriggers for the guard are of same size as the deck beams, and are cut through the hull, and fastened to them, running in far enough to get a good hold. The outer edge of the guard (where there is one) is framed stoutly to resist shocks. Where wide, the guard is held up by chains passing over braces heeled over on main deck.

The planking varies from 4 down to $1\frac{1}{2}$ inches, according to position, and style of boat: decking from $2\frac{1}{2}$ to $1\frac{1}{4}$ inches.

The hold is used exclusively for stowing freight; the main deck is for freight also. On it is located all the machinery and the deck crew, and second class passengers are quartered there. Above this,—from 10 to 18 feet, according to kind of cargo to be carried—is the boiler or saloon deck.

This is built of light matched stuff $\frac{7}{8}$-inch thick. On it is built a cabin for passengers, or sometimes, as in recent examples of freighters, a great cargo box for carrying freight. Above this again comes the hurricane deck, upon which another small cabin for the officers of the boat is built. This cabin is called the Texas. On top of it, and about amidships is the pilot house. In small boats, the Texas is often omitted, and the pilot house sits on the roof or hurricane deck. This deck is also very light—it is covered with canvas, which is painted and sanded, to prevent sparks from firing it.

They always arrange the upper deck so as to give from 20 to 30 feet of open forecastle. On this is located a steam capstan, while over the forward hatches a steam winch for freight hoisting is arranged. Bitts and Cavils are also on the forecastle, and derricks carrying the heavy spars used in shoving the boat off when aground. Heavy stanchions are heeled on the guard, or main deck when there is no guard, and reach to

the boiler deck. From the head of these hang heavy fenders. These are to prevent one boat's guard from riding over another's, for it must be borne in mind that these boats are often loaded, when the channel depth will permit, till the water stands on their guards.

For steering, a stern-wheel boat has a large balanced rudder amidships, and one or more common rudders on each side, their blades being coupled to the balanced rudder, which alone has a tiller.

Large steering wheels from 8 to 16 feet in diameter are used, and wire rope for tiller rope.

For machinery, non-condensing high pressure engines are the rule. Two cylinders are always used: they are slightly inclined. Poppett valves worked by cams are invariably used. Long wooden connecting rods strapped with iron are used. The boilers are fed by a special pumping engine, the feed water passing first into heaters, where it is met and heated by the exhaust steam. After leaving the heaters, the exhaust steam goes out into the air, or is used to force the draught in the chimneys. As the steam pipes are liable to be bent and twisted by the working of the boat, wrought-iron with copper bends is used.

The boilers are invariably cylindrical, and externally fired. They carry from 2 to 6 flues, of size depending on the diameter of the boilers, which ranges from 30 to 44 inches.

Below the boilers are two mud drums, and above is a steam drum. These are cylindrical, horizontal, and attached to each boiler by wrought legs. The feed goes into the after mud drum.

The chimneys (generally there are two) are as tall as possible.

The furnaces are arranged to burn either wood or coal.

The paddle shaft is of wrought-iron, with wrought cranks on each end.

From four to six cast-iron wheel flanges or centres receive the wooden arms of the wheel.

As a general rule, Western engineers prefer a long narrow bucket with a moderate diameter of wheel. A light dip is preferred, and they run at from 16 to 24 revolutions, depending upon size of engines.

The boiler pressures used, run from 100 to 150 lbs. depending on the size and thickness of shells. This matter is regulated by the United States Inspectors.

Expansion is carried on to a moderate extent. The steam follows from

one-half to three-fourth stroke: on the compound engines, of course a higher grade is obtained.

The expansion is done by a separate cam, which can be hooked on to the steam valve rock shaft. In handling, a separate rod connects the steam valves to the full stroke cam, which works the exhaust only when the cut-off is on.

This class of machinery is strong and light. Economy has been less consulted, as fuel along the river is cheap, and the mechanics have not the advantages of educated engineers to plan and direct their work.

C. R. S.

No. CLI.

GRAPHIC METHOD OF FINDING STRESSES IN LATTICE GIRDERS.

[*Vide* Plate XVI.]

By T. J. Dewar, Esq., *lately District Engineer, G. I. P. Railway.*

The following is a simple graphic method of finding the stresses on any description of lattice girder. The late Professor Rankine wrote to me on the subject in 1865 as follows:—

"I am much obliged to you for your diagrams of the stresses in Warren Girders, which are both interesting and useful, especially that for a travelling load, a case I do not recollect to have seen treated graphically before....."

The first diagram is simply a *polygon of forces*, and it appears strange that so simple a solution of a problem about which a great deal has been written, has not been published before.*

The second diagram being drawn to the same scale (of tons per foot run) as the first, shows in a very distinct way the greater stress produced by a travelling load, than by a fixed load of the same unit per foot run,

* Professor J. Clerk-Maxwell's graphic method (which is the same as that used in the first diagram), was published in the "Philosophical Magazine," April 1864, and a paper on this subject was read before the British Association for the Advancement of Science in 1867. It has since been largely used by other authors;—*e. g.*, Mr. W. Cawthorne Unwin (Wrought-Iron Bridges and Roofs, 1869)—Mr. R. H. Bow (Economics of Construction in relation to Framed Structures, 1873)—Captain Allan Cunningham, R.E., Professor of Mathematics, Thomason C. E College, (*vide* Roorkee Treatise on Civil Engineering, Section V., 1873,) &c. The second method (diagram No. 2) appears to be novel in regard to the mode of fixing the points D, F, H, J, &c., of the parabolic curve, and is perhaps more simple and rapid in execution, than the graphic methods of representing stresses in trusses under moving loads, adopted by the authors above quoted.—[

E GIRDERS.

Fig. (5a)

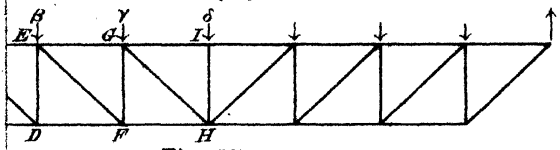


Fig. (5b)

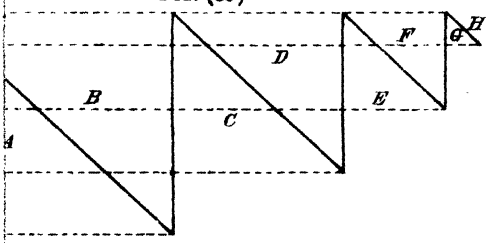


Fig (4a)

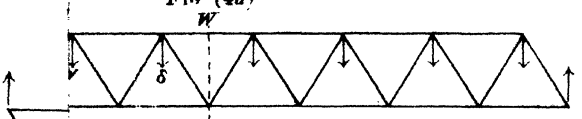
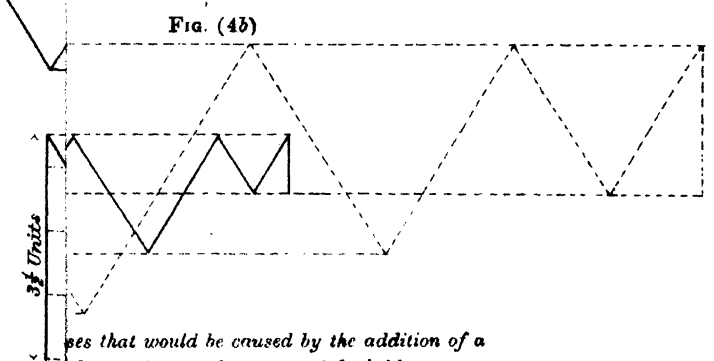
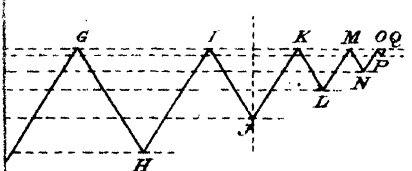


Fig. (4b)



ses that would be caused by the addition of a locomotive, at the centre of the bridge.



and also clearly exhibits the amount of stress on the diagonals near the centre of the span, where they are subject both to tension and compression.

1st Method.

Graphic Method of finding the Stresses in ang description of Lattice Girder, vide *Figs. (1a)* and *(1b)*.

On XX set off equal parts to represent the units of load at each apex of the half girder (each units = $\frac{1}{5}$th total load in the above example), and draw horizontal lines through the divisions. Commencing at X, draw a zig-zag parallel to the respective diagonals on the elevation, touching these horizontal lines in succession, as in the diagram.

The horizontal distances of the bottom angles of the zig-zag from XX represent the stresses on the successive divisions of the top or compression boom of the girder. The horizontal distances of the top angles from XX represent the successive tensions on the bottom tie. The diagonals represent the stresses on the ties and struts of the web.

(For example, the stress on FH on the elevation, is represented by the horizontal distance from XX of the apex between F and H in the diagram).

A few additional examples of the diagrams for a fixed load are given in *Figs.* 3*a*, 3*b*; 4*a*, 4*b*; 5*a*, 5*b*.

2nd Method.

Maximum Stress on each diagonal from a Partial or Travelling Load uniformly distributed, vide *Fig.* 2.

Draw AB as before, supposing the whole girder loaded, and AY at any angle. To any scale, set out A, 1 = 1; 1, 2 = 2; 2, 3 = 3; 3, 4 = 4; &c., ending at 7, 8 = 8, equals the number of loaded apices in the girder. Join 8, B, and draw lines parallel to it, through 7, 6, 5, &c., cutting AB in *u*, *v*, *w*, &c. Through these points draw horizontal lines, and a zig-zag parallel to the elevation, touching each in succession as before.

The diagonals will represent the greatest stress from a travelling load. Beyond the centre J, they represent the greatest compression on what would be a tie if the load were fixed, and tension on what would be a strut.

In a large bridge, the results of the two preceding methods should be added for the fixed and moving parts of the load.

T. J. D.

No. CLII.

SUTLEJ RIVER-TRAINING WORKS AT ADAMWAHAN.

[*Vide* Plates XVII., XVIII. and XIX.]

Report by H. C. GRAHAM, ESQ., *Exec. Engineer, on the training works, Sutlej River Conservancy Sub-Division, for the inundation season of* 1874.

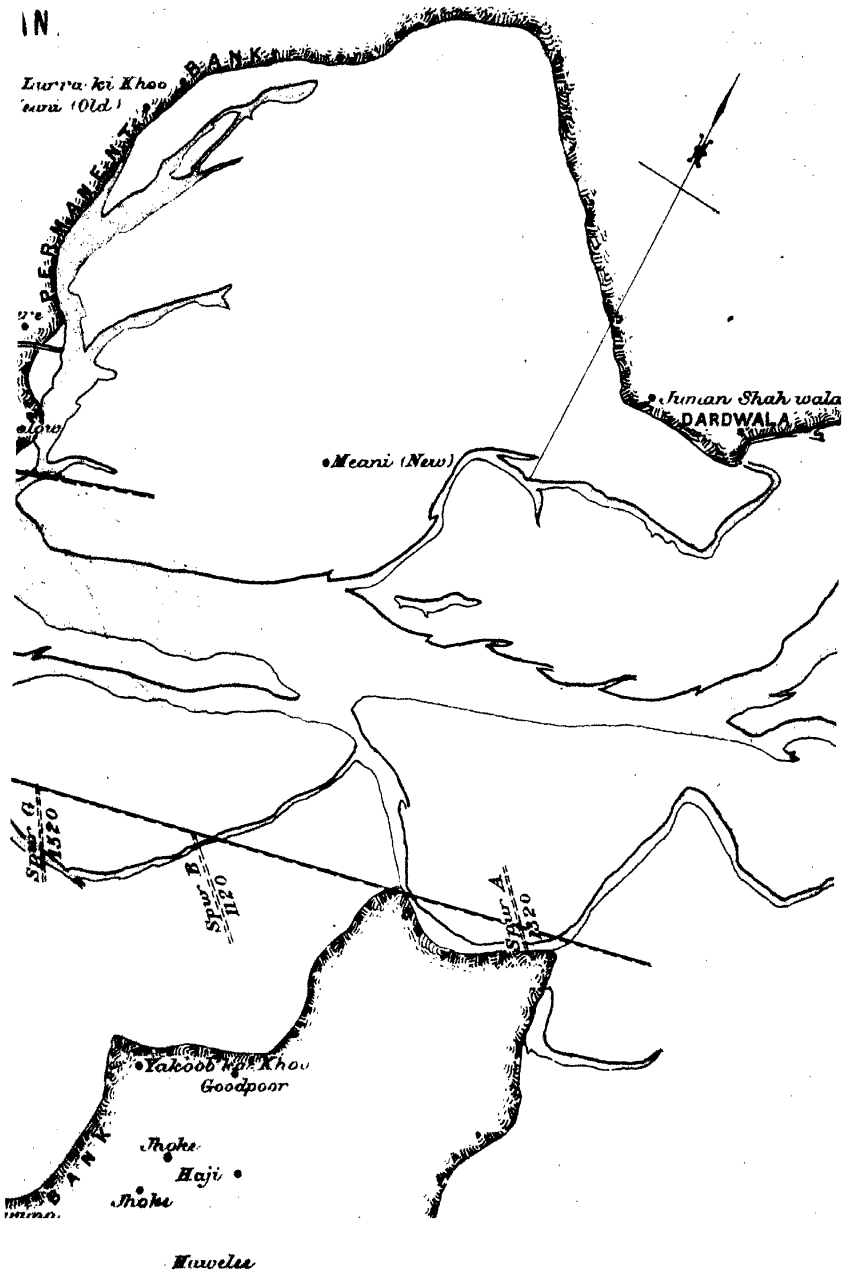
Dated 9th November, 1874.

THE position of the main and side channels of the river, near Adamwahan, at the beginning of the cold season of 1873-74, is fully shown on the Survey Map. It will be observed that, besides the main river, there are two principal side channels, one on each side of the main stream: that, on the right bank extending from Goodpoora to Adamwahan, while that on the left extends from beyond the limits of the survey, to about half a mile above the site of the Sutlej Bridge.

The principal protective works proposed for the past season were, for the right bank, spurs D, H, I and K, and for the left, spurs A, B, G, F, C, E and L, besides, of course, smaller local works which had to be decided upon from time to time, and for which no general design could be prepared.

The spurs just mentioned were intended to silt up the side channels and close them; thus confining the Sutlej to its main channel, straightening its general course for some miles above the bridge, and bringing the current down upon the latter in a normal direction.

On taking charge of this Division in June last, I found the river in flood, filling both main and side channels. The general direction of the strongest current was from above Dardwalla, on the right bank, to the left bank opposite new Meaneo, thence back to the right bank near Leihawan. From this it flowed with a very strong current along the right bank, to nearly the 2½-mile beacon, that is, to about the end of spur K


IN
Lurra ki Khoo
Lurra (Old)
B A N K
P. F. BOUNDARY
Junian Shah wala
DARDWALA
Meani (New)
Spur C
1320
Spur B
1320
Spur A
1320
Yakoob ki Khoo
Goodpoor
Thoke
Haji
Thoke
Mawelee

produced; then it crossed towards the left bank, which it reached at the lower end of the side channel, in which spur L is placed, and nearly half a mile above the bridge site. The current ran along this bank for more than three-fourths of a mile, and then turned sharply towards the right bank, which it struck above the village of Bhinda.

At that time, spur D was partly finished, and a small tree spur extended from the right bank to No. 4 trial well.

The other spurs were put in hand as rapidly as possible wherever there was water enough for them to act.

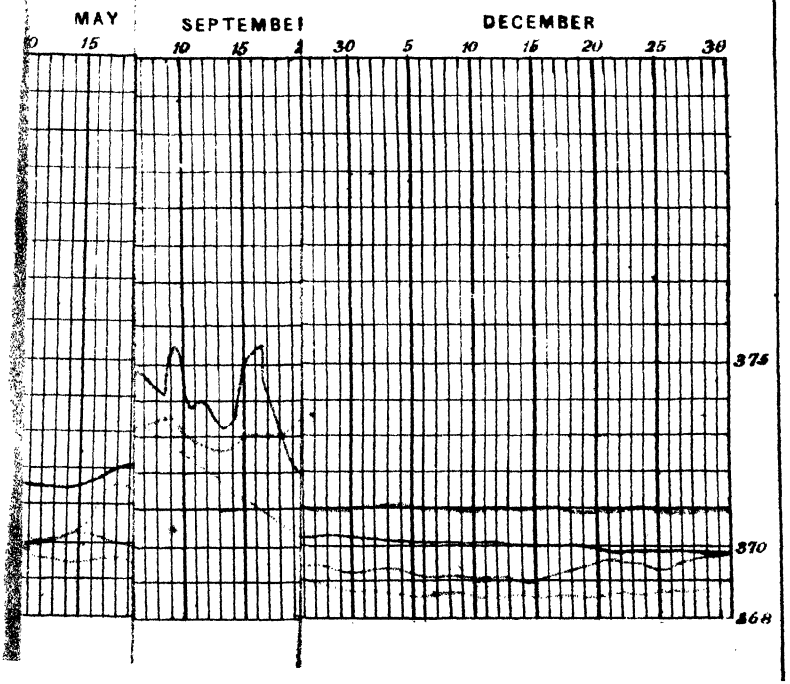
A short description of the spurs may here be given. It was intended to adopt Colonel Brownlow's system as far as possible, to imitate the growth of weeds, to obstruct the current without suddenly deflecting it, and thus to silt up the side channels. To effect this, it was necessary to provide the weed itself, with means of anchoring it, and of keeping the upper end from sinking through being water-logged. This was done in the following manner:—The weed consisted of a strong rope or hawser of moonj, generally 8 inches in girth, and of a length varying with the depth of water and strength of current up to 90 feet, with from two to ten bushes or small trees lashed to it by their butts, the largest bushes being placed lowest. The hawser was made fast to an anchor formed of a netting from 6 to 2 feet square, of 2 to 2½-inch moonj rope, with meshes from 4 to 6 inches square; in this, loose bricks were built up as closely as possible, from 16 to 65 cubic feet being used in each net. To keep the weed from sinking when the hawser and bushes became water-logged, one or two empty casks were lashed to the upper end of the former. The casks, as a rule, remained perfectly tight, but as a precaution, they were wetted daily, where it could be done without much expense.

Besides the above, fixed brushwood spurs and net spurs were also used. The former were simply constructed of bushes and trees laid with their butts up-stream, and kept in place by some of the anchors above described, to which they were made fast; as the bushes settled down, others were piled over them. The net spurs were made of netting similar to that above-mentioned, in lengths of 100 feet by from 6 to 20 feet wide, several being sometimes joined together. A hawser was passed through the lower meshes for the whole length of the net, and another through the upper ones; to the former anchors of the kind already described were made fast, and to the latter casks.

The only spur which was laid entirely upon Colonel Brownlow's system was D; all of the others were of a mixed description; Colonel Brownlow's weeds being used wherever the water was deep enough to float a cask with the hawser and bushes attached to it, which required at least 6 feet depth. The other parts were partly fixed brushwood spurs in shallow water, and in a few places net spurs; the latter were, however, generally used to strengthen the other works, and were generally placed further up-stream than the others.

A short account of the smaller defence works which were found necessary during the inundation may now be given. Towards the end of July, the main current began to work over higher up on the right bank between the bridge site and the village of Bhinda, about a mile below Adamwahan. The inundation of 1873 had left here a very deep channel close to the bank; in July last, the depth varied up to 26 feet; 20 and 22 feet being commonly met with. On the opposite side of the river the water was quite shallow, and a large shoal extended fully half way across the river; this reflected the current towards the right bank, and the point where the current struck the bank appeared to be moving higher up-stream, as just stated.

It appeared necessary to stop this, otherwise a repetition of the cold-weather channel of October 1873 might be expected in October 1874. A glance at the plan will show that this was to be avoided, if possible. In order to prevent this, a number of the Brownlow weeds were placed in the river, in about 8 feet of water, and about 200 yards from the right bank, extending in three lines parallel to the shore. At the same time a net spur was placed in the river, so as to deflect part of the current, and throw it upon the shoal opposite. The effect of these was almost all that could be wished; the net spur was unfortunately carried away by the strong current, after doing some good; but the weeds stood well, and drove the current outwards beyond the present right bank; they so effectually shut off from the current the space between them and the former right bank, that by the end of the season the deep channel from Adamwahan to below Bhinda became silted up, and has now water in it at intervals only, and there only a foot or two in depth. In August the flood of the 12th formed a channel almost identical with that of last cold season, extending from No. 1 trial well to the right bank. I am strongly of opinion that the main channel would have gone over entirely to the


MAY
SEPTEMBER
DECEMBER
0
15
10
15
1
30
5
10
15
20
25
30
375
370
368

right bank below the bridge site, if the deep water there and lower down had existed at the time, that is, if the deep channel had not been greatly silted up by the weeds just referred to. As it was, we had great difficulty in keeping the main current outside No. 1 trial well; a net spur, 300 feet long and 10 feet wide, with 60 casks, and as many anchors of 50 cubic feet each, was put in above the well, and stood for about a fortnight, when the whole was carried away by the current. It had, however, done its work; the side channel had greatly silted up, and the danger was over for the time.

The other smaller works were principally near Goodpoora, and for about a mile above Adamwahan. On the 24th August the river was in flood, and threw up a sand bank opposite Goodpoora, deflecting the main current directly upon the right bank above that village, cutting the bank away rapidly, and making it evident that, unless proper means were adopted at once, the comparatively straight channel of the main river then existing from Goodpoora to below Adamwahan would be destroyed, and an unknown number of bends in the cold-weather channel would be the result.

It unfortunately happened, that on the 31st August all the unskilled labourers employed in the Division struck work, and materials consequently ran short. What could be done with the means at hand was done as rapidly as possible, but the channel still remains close to the right bank just above Goodpoora. Had this been all, it would have been of little consequence; but the current striking on the bank at Goodpoora was, of course deflected, to the left bank at spur L; rebounding from this, it struck the right bank at, and a little above, Adamwahan. At this time the bank here nearly coincided with the north edge of the intended cold-weather channel as marked by a dotted black line on the plan of last cold season's survey. The current striking this rapidly, cut it away; and in order to prevent the whole of it being washed away, it was necessary to line the edge with fascines, and to lay short weed spurs at intervals along the bank at Adamwahan for nearly two miles. Materials not being ready at Goodpoora, and near spur L in sufficient quantities, it was necessary to confine to the bank near Adamwahan our efforts to prevent further erosion. I need hardly say that this is not the proper method to follow in general; in this instance it was a matter of necessity. From 5th to 25th September, every effort was made to defend the bank, and to throw the

current further out into the stream, and with success. A large quantity of materials was used in this work, 575 weeds having been laid down.

The effect of the principal spurs D, H, I and K on the right bank, and of A, B, G, F, C, E and L on the left, has been satisfactory, the two side channels having almost entirely silted up. That on the right bank is completely closed at the head by spur D, and between that and spur H, there are only a few pools of water of small size in the side channel; between spurs H and I there is only one small pool; from that to Adamwahan it is quite dry. At the latter place there is some water still, about 4 feet deep; last year it was 13 feet. On the left bank the effect is also decided, the channel has silted up greatly, and there is no continuous stretch of water in it, and at the lower end, the great bend from which the Norungah Canal drew its supply of water during last cold season is now dry, and the Bhawulpoor State Authorities have been obliged to continue the canal across the former side channel, and to draw their supply from the main river between spurs E and L. For the same reason, the Khan Wah which formerly tapped this channel, has been lengthened, so as derive its cold weather supply from the main river at spur F.

The present state of the river will be fully shown when the survey now in progress has been plotted; in the meantime, I may state roughly that the general direction of the current is as follows:*—It is nearly in the same place as last cold weather at the mouth of the channel, in which spur A is placed; from that it strikes towards the mouth of the Dhund, immediately above Goodpoora; thence it bends gradually towards the left bank near spur E produced; thence towards the right bank, near the place where the 2¼ mile beacon stood, or a little below spur K produced. From this it runs in a direction almost exactly normal with the intended bridge for nearly four miles, half of this distance being above, and half below bridge, the channel at the crossing being nearer the right than the left bank. The sites of both abutments, and of four piers on the north, and seven on the south of the existing cold-weather channel, are high and dry.

The expenditure up to 1st instant since the beginning of March 1874, has been Rs. 80,546, of which Rs. 24,176 had been expended before I took over charge of the Division; leaving Rs. 56,370 as expended during the last inundation. The sum of Rs. 80,546 represents the cost of 16,819 lineal feet of spurs of all kinds, including every expense connected

* Vide *Plate* XVII.: present state of river being marked *pink*.

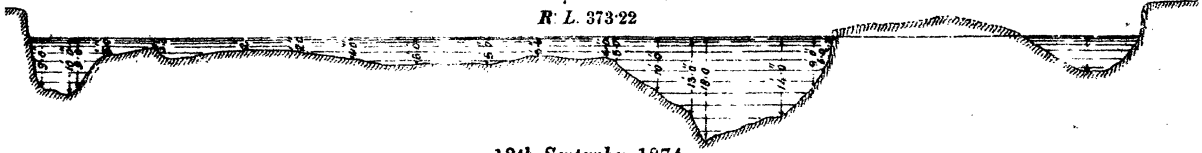
SALAR JUNG BA

SUTLEJ RIVER-TRAINING WORKS AT ADAMWAHAN.

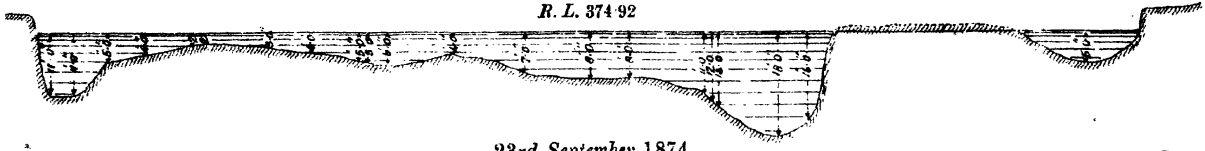
(Sutlej Bridge Division, Cross Section of the River Sutlej at the Adamwahan crossing 1874).

SCALES
Horizontal 600 feet = 1 inch.

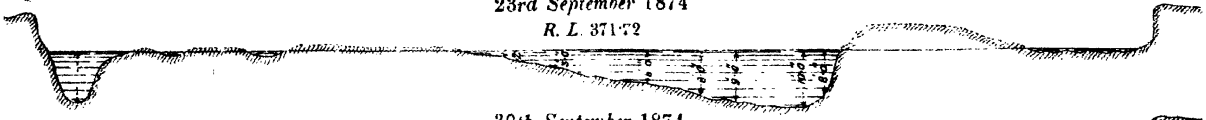
14*th September* 1874
R. L. 373·22



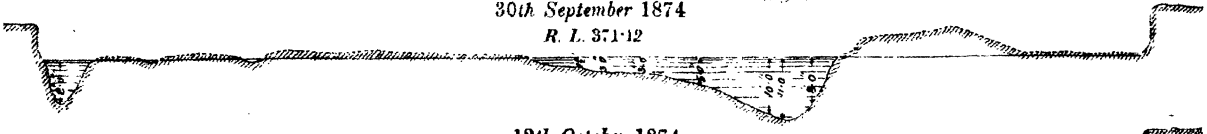
18*th September* 1874
R. L. 374·92



23*rd September* 1874
R. L. 371·72



30*th September* 1874
R. L. 371·12



12*th October* 1874
R. L. 370·42

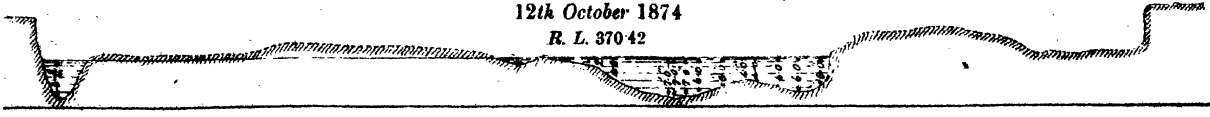


PLATE XIX.

with them, except Departmental supervision; and is equal to Rs. 4-8-2 per foot run. The different descriptions of spur cost almost exactly the same sum per lineal foot; the weeds being, if anything, more expensive than the others, and the brushwood spurs being the cheapest of all. This comparative cheapness is, however, more apparent than real, as the brushwood spurs were used in the shallowest water. With similar depths, the cost may be taken as the same throughout.

I have reason to believe that the above rate may be reduced in future work by using more material in the first instance, and avoiding the heavy expenses incurred for repairs.

Note by Lieut.-Col. F. W. Peile, R.E., *Engineer-in-Chief, Indus Valley (State) Railway.*

The conservancy operations of the past season have, I am glad to say, proved very successful.

The position to which the channel has been driven in the neighbourhood of the bridge site, is as favourable as could be desired; instead of having water under the Adamwahan bank of various depths up to 22 feet, we have now a dry sand bank, and the deep *dhund* forming an elbow on the Bhawulpore side, from which the Norungah Wah was supplied last year, has also been silted up.

The river runs in a very straight reach for four miles, the bridge occupying the centre, and it is confined at the bridge site to a single channel, nearly at the centre of the bridge.

All the side channels which caused so much apprehension in the bays on either bank below Shahki Busti and Goodpoora have been closed.

I consider the results of this season's operations are very encouraging, and afford good grounds for the hope that the oscillations of the river may be restrained with some degree of certainty between fixed limits; but I am still of opinion that a considerable expense must be incurred in some more permanent and solid constructions near the bridge, which may serve to give some security to the approaches, especially on the Bhawulpore side, in case of the failure of the temporary obstructions.

The great distance of the bridge head from the main bank, (1½ miles,) will cause any work undertaken on the Bhawulpore side to be costly.

I am glad to be able to report that "Brownlow weeds" as we now call them, have proved very effective.

Note by LIEUT.-COL. E. C. S. WILLIAMS, R.E., *Director of (State) Railways.*

These operations have been eminently successful so far.

On the plan, which is herewith returned, is marked what is considered necessary in order that the training works may be in the best possible condition to meet the floods of the coming season. The spur M, whose position on the plan has been slightly altered, should be considered as the head-work of the operations on the left bank of the river. It is perhaps unnecessary to carry out the whole of this spur at once, but the portion which crosses the channel between *a* and *b*, should be carried out before next flood, and the remainder which is shown dotted, must be carried out hereafter, should the channel, at present closed by the spur A, show signs of re-opening. Lower down the spur F, slightly altered on the plan, should be carried out before the next rains, and possibly also other spurs either at D^1 or else at D^2, or perhaps at both places will be found necessary.

It is possible that the next floods may baffle all measures to train the river, and unforeseen operations may have to be undertaken, but I trust that by the provision of the above-mentioned spurs, you will be found fully prepared.

The success of last season's operations depended mainly on the exertions of Mr. Graham, in collecting the necessary material, and applying it under circumstances of much difficulty.

No. CLIII.

DEPTH OF WELL-FOUNDATIONS.

By Capt. Allan Cunningham, R.E., *Hony. Fell. of King's College, Lond.*

[The notation here used is mostly the same as in Rankine's Manuals of Applied Mechanics and Civil Engineering. References are given to these and to the Author's Pamphlet* on Well-Foundations].

1. The present Paper is an investigation of the necessary depth of Well-Foundations with vertical sides in yielding soil, *sufficient only to prevent subsidence.*

[The question of the depth necessary to secure Stability of Rotation when exposed to high wind, current-pressure, and other horizontal forces *is here neglected*, forming a separate Problem which has been already fully considered in the Author's Pamphlet on Well-Foundations. The question of Stability of Rotation is believed to be the more important of the two].

2. It seems obvious that the sole Supporting Forces which prevent subsidence of a Well-Foundation with vertical sides are—

1°. Vertical upward Re-action (R) of the subsoil against the base,—including in this of course fluid-pressure, if water has access to the base (as in a pervious subsoil).

2°. Vertical Friction (F) of the subsoil against the masonry.

It is clear that if—

R = Maximum vertical Re-action developable in subsoil against base of one Well.

F = Maximum vertical Friction developable in subsoil against sides of one Well.

* No. LXXXIII. of "Professional Papers on Indian Engineering," Second Series.

W = Weight of one Well with its Superstructure and Live Load, then the Well must sink so long as R + F < W, and will sink no further when R + F = or > W, and that if R, F, W be expressed in terms of the depth, then the solution of the equation

$$R + F = W, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1),$$

will give the value of the least necessary depth, to prevent actual subsidence, and on the other hand for a given depth the ratio

$$(R + F) \div W = \text{Factor of Safety} \quad \ldots\ldots\ldots\ldots (1A),$$

or shows the excess of the Supporting Forces over the Weight of Well and Superstructure.

3. *Internal Subsoil-pressure.*—The internal subsoil-pressure at any depth x below the bed is the sum of the pressures due to three causes,

1°. Atmospheric pressure.

2°. Pressure due to depth of water in stream.

3°. Internal pressure in the subsoil due to its own weight.

The first of these may be neglected for all practical purposes, and it is wise to neglect the second also, as though increased depth of water undoubtedly increases the subsoil internal pressure *cæteris paribus* in proportion to the depth of water, still this increase cannot be depended on, and it is more than probable that certain physical causes, such as increased permeation of the soil, tend (with increased head of water) to loosen the coherence of a pervious subsoil—which is the case in hand—and *pro tanto* diminish its power of resisting pressure, and of yielding friction.

It will, therefore, be assumed that the internal subsoil pressure is that due to the third cause, *i. e.*, to its own weight only. In order to obtain a definite solution moreover it will be supposed that *the subsoil is homogeneous*, and that the *level of the bed is maintained uniform*, and that the *quality of the subsoil is invariable*, that is to say, that its power of resisting pressure and yielding friction are unaffected by any change in the depth of water.

These limitations make the quantities ϕ, μ, w, which express the physical properties of the subsoil in the following investigation constant.

[*Limits of applicability.*—The above limitations must be carefully attended to, as unless they are approximately fulfilled, the formulæ deduced on these premisses are of course inapplicable].

4. Let A = area of base of Well *in sq. ft.*,

C = circumference of Well *in ft.*,

w' = heaviness of masonry *in lbs. per c. ft.*,

Let d = depth of base of Well below surface of soil *in ft.*,
w = weight of masonry of one Well above surface of soil, with weight of superstructure and Live Load *in lbs.*

Then, since the Well has vertical sides—

Ad = volume of masonry below surface of soil *in c. ft.*,
$w'Ad$ = weight of masonry below surface of soil *in lbs.*,
Cd = surface of masonry in contact with soil *in sq. ft.*,

$$\therefore \quad W = w + w'Ad, \qquad \ldots\ldots (2).$$

Let ϕ = angle of repose of sub-soil,
μ = co-efficient of friction between sub-soil and masonry,
w = heaviness of sub-soil *in lbs. per c. ft.*,
x = any depth below surface of soil *in ft.*,

[*N.B.*—It is intended that ϕ, μ, w should be quantities expressing the physical properties of the actual material of the sub-soil, in its actual state of physical aggregation, *i. e.*, including in the term 'sub-soil' *all* the constituents whether solid or liquid].

Then by Rankine's Applied Mechanics, Art. 199,

$$wx\frac{1+\sin\phi}{1-\sin\phi} = \left\{\begin{array}{l}\text{maximum sub-soil } \textit{horizontal} \text{ pressure-intensity} \\ \text{at depth } x.\end{array}\right.$$

$$= \left\{\begin{array}{l}\text{maximum sub-soil normal pressure upon the} \\ \text{masonry at depth } x.\end{array}\right.$$

$$\therefore \ \mu wx\frac{1+\sin\phi}{1-\sin\phi} = \left\{\begin{array}{l}\text{maximum vertical friction-intensity between} \\ \text{masonry and sub-soil at depth } x.\end{array}\right.$$

Thus the maximum vertical friction-intensity developable at any depth (x) varies as the depth, or is a '*uniformly-varying*' *stress.*

Hence by the known laws of such stress,—

$$\left.\begin{array}{l}\text{Mean intensity of max. vertical friction over a vertical plane of depth } d,\end{array}\right\} = \tfrac{1}{2} \text{ of } \left\{\begin{array}{l}\text{intensity of the same at} \\ \text{depth } d,\end{array}\right.$$

$$= \tfrac{1}{2}\mu wd\frac{1+\sin\phi}{1-\sin\phi}$$

$$\therefore \text{ Total Vertical Friction against sides of Well of depth } d, \Big\} = \tfrac{1}{2}\mu wd \cdot \frac{1+\sin\phi}{1-\sin\phi} \cdot Cd$$

$$\therefore \quad F = \tfrac{1}{2}\mu w\frac{1+\sin\phi}{1-\sin\phi} \cdot Cd^2, \qquad \ldots\ldots (3).$$

Also by Rankine's Applied Mechanics, Art. 199,

$$wd\left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2 = \left\{\begin{array}{l}\text{max. subsoil vertical (upward) pressure-} \\ \text{intensity at depth } x.\end{array}\right.$$

$$\therefore \text{ Vertical Re-action of soil against base, } \Big\} \text{ or } R = wd \cdot \left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2 \cdot A, \ldots (4).$$

It is interesting to remark that R varies as the depth, and that F varies as the square of the depth, so that F increases much more rapidly with the depth than R; also that in very yielding soils for which ϕ is of course small, $\frac{1+\sin\phi}{1-\sin\phi}$ is not much > 1, so that if the depth (d) is *large*, as is necessarily the case with slender Wells, F is a much larger quantity than R, which proves what is *already practically known*, (*see* Art. 13 of Paper LXXXIII. on Well-Foundations,) that—

"The Vertical Friction is the principal Supporting Force in case of slender Well-Foundations in waterlogged sand".

Hence substituting from (2), (3), (4) into (1), the resulting equation for finding d proves to be an ordinary quadratic

$$\tfrac{1}{2}\mu w \frac{1+\sin\phi}{1-\sin\phi} \mathrm{C}d^2 + w \cdot \left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2 \mathrm{A}d = \mathrm{w} + w' \cdot \mathrm{A}d, \quad \ldots (5).$$

Writing $\frac{1-\sin\phi}{1+\sin\phi} = k'$, ... (6).

$$d^2 + \frac{2}{\mu}\left(\frac{1}{k'} - k' \cdot \frac{w'}{w}\right)\frac{\mathrm{A}}{\mathrm{C}}\, d = \frac{2k'}{\mu w} \cdot \frac{\mathrm{w}}{\mathrm{C}}, \ldots\ldots (7),$$

the *general* equation from which d is to be found.

Case of cylindric Well.—If the submerged portion of the Well be a cylinder, of radius r (in feet), then $\mathrm{A} = \pi r^2$, $\mathrm{C} = 2\pi r$, and Eq. (7) becomes—

$$d^2 + \frac{1}{\mu}\left(\frac{1}{k'} - k' \cdot \frac{w'}{w}\right) rd = \frac{k'}{\mu w} \cdot \frac{\mathrm{w}}{\pi r}, \ldots\ldots (7\text{A}).$$

5. *Case of Quicksand.*—This is by far the most important case in practice—being that of many large Indian rivers. Adopting the conclusion (*v. supra*) that R is a very small quantity compared with F, and may as an approximation be neglected, the fundamental equation (1) becomes

$$\mathrm{F} = \mathrm{W}, \ldots\ldots (8),$$

and Eq. (7), (7A) become

General case. $$d^2 - \frac{2k'}{\mu} \cdot \frac{w'}{w} \cdot \frac{\mathrm{A}}{\mathrm{C}}\, d = \frac{2k'}{\mu w} \cdot \frac{\mathrm{W}}{\mathrm{C}}, \ldots\ldots (9).$$

Cylindric Well. $$d^2 - \frac{k'}{\mu} \cdot \frac{w'}{w}\, rd = \frac{k'}{\mu w} \cdot \frac{\mathrm{W}}{\pi r}, \ldots\ldots (9\text{A}).$$

Observe that the error made in the value of d resulting from Eq. (9), (9A), due to neglecting R, is on the side of safety.

[*N.B.*—The value of d resulting from Eq. (7), (7A), (9), (9A), is of course the very least depth under all the hypotheses at which the Well would just cease to sink—in fact it might be said to be floating at this depth, its Weight being their just balanced by the Re-actions of the soil].

6. *Imperfection of the data.*—The values of the physical quantities ϕ, μ, w' are (in the author's opinion) not at present sufficiently well known for the particular material—waterlogged sand—to admit of the Results here investigated being satisfactorily applied to this case. It is supposed there could be no difficulty in determining w' (the weight per cubic foot of the actual subsoil) by actual trial, but the determination of ϕ and μ could only be done indirectly, and would be a matter of considerable difficulty.

7. *Example.*—In the Káli Naddí Viaduct, a Weight of 414·4 tons rests on each Well above level of bed; the wells are 12′ cylinders; the subsoil is said* (by the Resident Engineers) to be of such a nature that

$$\phi = 15°, \mu = \tfrac{1}{3}, w = 100 \text{ lbs. per c. ft.}$$

Find least depth (d) necessary to prevent actual subsidence.

Solution. Here $k' = \dfrac{1 - \sin\phi}{1 + \sin\phi} = \cdot588$, $\dfrac{1}{k'} = 1{\cdot}7$ (Rankine's Applied Mechanics, Art. 201), $\dfrac{1}{\mu} = 3$, $r = 6'$, $w' = 120$ lbs. per c. ft., $W = 414{\cdot}4 \times 2240$ lbs.

Hence Eq. (7A) becomes

$$d^2 + 3 \times \left(1{\cdot}7 - \cdot588 \times \frac{120}{100}\right) \times 6d = \frac{3 \times \cdot588}{100} \times \frac{414{\cdot}4 \times 2240}{\frac{22}{7} \times 6}$$

whence $d^2 + 18d = 868{\cdot}3$, *nearly*.

$$\therefore d = -9 \pm \sqrt{868{\cdot}3 + 81} = -9 \pm \sqrt{949{\cdot}3} = -9 \pm 30{\cdot}8$$

$$\therefore d = 21{\cdot}8, \text{ nearly.}$$

[*N.B.*—This is the very least depth at which under all the hypotheses the Well would just *cease to sink*—in fact it might be said to be *floating* at this depth, its weight being just balanced by the Supporting Forces].

8. *Determination of the constants* ϕ and μ.—The values of these quantities might be determined by experiment, by simply recording a sufficient number of observations *during the progress of sinking a Well* as follows:—

It is known that in many cases in the progress of sinking, the subsoil is *completely removed* from underneath the base of the Well, at which time the Vertical Re-action (R) of the subsoil can only be the hydrostatic pressure due to the head of water within the well. And supposing the Well to have vertical sides both externally and internally, and in addition to previous notation,

Let a = Area of hollow at base of Well in square feet,

w'' = heaviness of water = 62½ lbs. per cubic foot,

* *Remark by Author.*—It seems doubtful if the values $\phi = 15°$, $\mu = \frac{1}{3}$, can be depended on, as they are apparently the figures for *masonry in contact with moist clay* of Art. 110 of Rankine's Civil Engineering. The value $w = 100$ lbs. per c. ft., also seems very large for quicksand.

d'' = head of water inside* Well above the base.

Then $R = w''(A - a)\,d''$, ... (10).

$W = w + w'(A - a)\,d$, ... (11).

Then in general during the progress of sinking, so long as subsidence is not taking place, $R + F < W$, but in the state *just before actual subsidence occurs*,

$$R + F = W,$$

whence, $\frac{1}{2}\mu w \cdot \frac{1+\sin\phi}{1-\sin\phi} \cdot Cd^2 + w'' \cdot (A - a)\,d'' = W,$

$$\therefore \mu \cdot \frac{1+\sin\phi}{1-\sin\phi} = 2 \cdot \frac{W - w''(A-a)\,d''}{wCd^2} = 2 \cdot \frac{w + (w'd - w''d'') \cdot (A-a)}{wCd^2} \Bigg\} \text{..... .....(12)},$$

in which equation w, w', w'', C, A, a are all constant, and are known quantities, and w, d'', d are quantities which vary during the progress of sinking, and are the *quantities to be observed*, whilst μ, ϕ are the quantities sought.

It may be objected to the calculation here proposed that there is *only one equation* (10) to determine *two* quantities μ, ϕ. The Result of calculation from Eq. (10) will of course give *only the value of the quantity* $\mu\frac{1+\sin\phi}{1-\sin\phi}$, (not of either μ, or ϕ separately,) whereas the use of the general equation (7) or (7A) above, requires a knowledge of both μ and ϕ.

It must be observed however, that the quantity found $\left(\mu \cdot \frac{1+\sin\phi}{1-\sin\phi} = \frac{\mu}{k'}\right)$ from Eq. (10), is sufficient for the determination of the Total Vertical Friction (F) by Eq. (3), and that in the very case of most practical importance—that of Well-Foundations *in quicksand*—this has been explained above (Art. 4, 5) to be by far the most important element of vertical Re-action, and is all that is wanted for solution of the special equations (9) or (9A) for quicksand, so that the application of this Method though insufficient *in general* (*i. e.*, for any soil) would be of great importance for quicksand.

If a sufficient number of observations were obtained of the quantities

* This is not necessarily the same as the head outside the Well.

w, d'' corresponding to different depths (d), the correctness of the Theory could also be tested.

9. *Practical Remark.*—Great care would be necessary to use only such observations of w, d'', d as were really suitable for the object intended. It is absolutely necessary (Art. 7 and 8) that—

1°. There should be no subsoil below the base of the Well at time of observation.

2°. The observations be recorded just at the time that actual subsidence is beginning.

3°. The *quality* and *state of aggregation* (Art. 8) of the subsoil at Well-base be also simultaneously recorded.

4°. The *mean level* of actual bed of the stream near the masonry be also simultaneously recorded.

Unless these precautions be carefully attended to, the resulting values of $\mu \div k'$ (for the same soil of course) would be so discordant, as to be obviously inaccurate, and it would be hopeless to attempt to reconcile them.

But it seems probable (to the author) that the observations do not admit of accurate determination, in consequence of the difficulty of ascertaining whether the necessary conditions (Art. 3, and 1°, 2° above) were approximately fulfilled, so that some discordance must be expected in the results,—as is always the case in the determination of all physical constants, and it would probably be a tedious work to reconcile them.

10. *Importance of the result.*—The importance of the result aimed at seems however to make it advisable to attempt to determine this quantity ($\mu \div k'$) for waterlogged sand, such as is common in Indian rivers. If this constant were known, the Problem of STABILITY OF ROTATION of Well-Foundations treated of in the author's Paper, No. LXXXIII. of these Professional Papers, could also be *completely solved*, so that the solution of the Problem of necessary Depth of Well-Foundations in quicksand *in all its aspects* could then be effected with some chance of approximation.

ADDENDUM TO ABOVE PAPER.

With the view of testing the Theory advanced above in the interest of Engineering Science, and of determining the value of $\mu \div k'$—as to the importance of which see Art. 9—for given soils (especially *quicksand*), the author will be glad to receive from such Engineers as are in a position to supply them, detailed records of observations of the quantities (w, d'', d) indicated in Art. 7, such as could easily be recorded during the progress of sinking Wells, and which could probably be obtained from the existing records of the progress of sinking of Wells already sunk. Particular attention is requested to the Remark in para. 9.

It is requested that the records of observation be made out in following form.

RECORD OF PROGRESS OF SINKING WELL-FOUNDATION NO.—AT-

1°. *Material of Well.*—(Brick in cement, or mortar, &c., Cast-iron, &c.)
2°. *Heaviness of ditto,*—in lbs. per c. ft. = w'.
3°. *Nature of Well-Surface.*—(Rough brick, smooth brick, &c.)
4°. *Nature of subsoil near bed.*—(Quicksand, Firm wet sand, Dry sand, (Argillaceous sand, Wet clay, &c., &c.,)
5°. *Heaviness of ditto,*—in lbs. per c. ft. = w.
6°. *Area of plan of Well,*—in sq. ft. = A.
7°. *Area of hollow heart of ditto,*—in sq. ft. = a.

A horizontal section, and a vertical (diametral) section of Well—both drawn to scale—should accompany. The two quantities w, w' should be determined by actually weighing a cubic foot or more of the masonry, and of the subsoil; (the latter being as nearly as possible in its natural state, including natural absorbed water).

In the accompanying Table, the quantities H, d', d'', w_1, w_2, should be written from actual observation: they should all be the values *just before subsidence:* it would be no use recording them *during subsidence.*

The column headed w need not be filled in, unless the subsoil can be brought up in a tolerably natural state, *e. g.*, it would be of no use entering the weight of a cubic foot of "slush".

RECORD OF PROGRESS OF SINKING WELL-FOUNDATION NO.—AT———

Date.	Hour of subsidence.	Subsidence in feet.	Values just before subsidence.							Character of subsidence.	Subsoil at Well-base.		Remarks.
			Height of Well,	Depth of Well-base below mean Bed,	Depth of water in Well,	Weights in lbs.					Description.	Heaviness in lbs. per c. ft.	
						Load,	Superstructure,	Well,	Total,				
			(Measured from Well-head to Well-base).	(By "mean Bed" is meant the average level of Bed within say 30 feet of Well).	(From water-surface (inside Well) to Well-base).	(By this is meant the temporary load of all sorts intended solely to sink the Well).	All temporary superstructure, whether masonry, or staging intended to carry the Load.	This may be found by calculation: in a Well *with vertical sides*, $w_3 = w'$. $(A - a)$. H.	$W = (w_1 + w_2 + w_3)$.	To be described as— "Very sudden", "sudden", "gradual", "slow", &c.	By actual weighing of a cubic foot or more, as nearly as possible in the state in which it is supposed to exist at the Well-base.		
			H.	d.	d''.	w_1.	w_2.	w_3.	W.		Should be described as— "Quicksand", "Firm wet sand", "Dry sand", "argillaceous sand", "clay", "kunkur", &c., &c.		

A. C.

No. CLIV.

DUFF'S KITCHENER FOR BRITISH TROOPS.

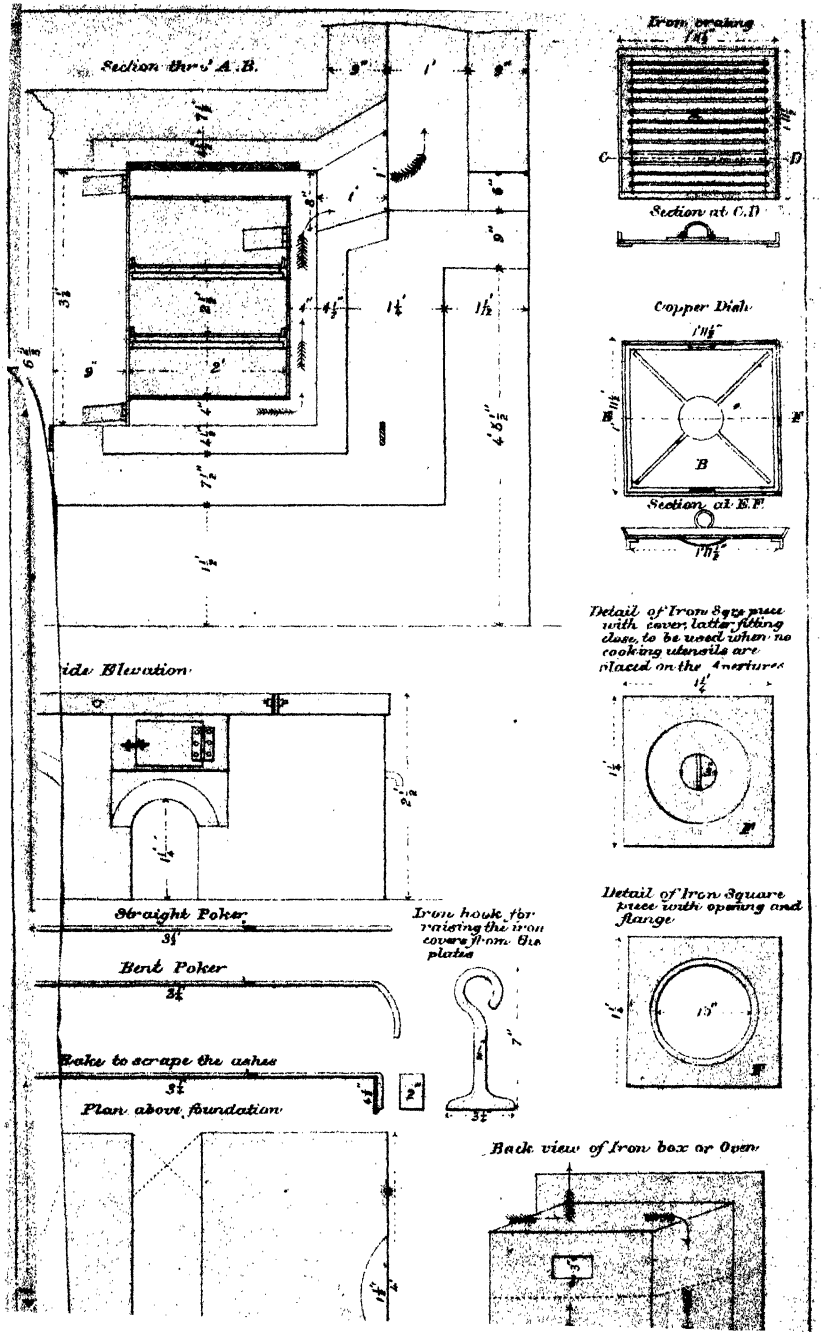
[*Vide* Plates XX., XXI. and XXII.]

By Capt. J. L. L. Morant, R.E., *Assoc. Inst. C. E., and* F.R.G.S.

This Kitchener was invented by the late Doctor C. M. Duff, M.D., of the Madras Medical Service, so long ago as 1857, but it does not seem to have received the attention it deserves. Three have recently been erected in the European barracks at Wellington on the Neilgherries, and have worked for two years very satisfactorily. They replaced the generally used open arched fireplaces, in which the food was not at all well cooked, was often smoked and dirty, and the heat and mess in the kitchen great.

A Duff's Kitchener aims at cooking for large numbers with a single closed fire, and at combining economy of fuel with simplicity of management, easy control, and external coolness. On the whole it fulfills these conditions. For example, the Wellington Ranges consume only two-thirds of the firewood used before they were erected. This reduction might with more care and supervision be still further lowered to one-half of the original consumption. They now use up two lbs. of green firewood per man per diem. The rooms in which they have been erected, although in some respects unsuitable and ill-ventilated, are seldom heated to such an extent as to make them unpleasant. The ranges generally feel cool at a short distance. The cookery they produce is clean, good, and effected rapidly. It is greatly preferred by the soldiers to that which they obtained from the former open fireplaces. These ranges boil, broil, roast, stew, steam, supply hot water, and bake bread and pastry.

The design of the Kitchener.—An iron band encircles the range, binding


Section thro' A.B.
Iron grating
C
D
Section at C.D
Copper Dish
E
F
B
Section at E.F
Detail of Iron Sauce pans with cover, latter fitting close, to be used when no cooking utensils are placed on the 4 ventures
Side Elevation
Straight Poker
Bent Poker
Iron hook for raising the iron covers from the plates
Rake to scrape the ashes
Plan above foundation
Detail of Iron Square piece with opening and flange
Back view of Iron box or Oven

the masonry together, and forming a sort of cope or edge which makes it very durable. *The Boiler.*—Its bottom rests on brickwork, and three of its sides are bounded by it. The fourth and naked side is in direct contact with the fire in the grate. The lid which forms part of the cooking hearth should be provided with a handle, and be hinged on the side next the grate, so that at pleasure potatoes and other vegetables may be boiled in it. Its hot water might at other times be conveyed by piping to some adjacent parts of the barracks for hot baths. *The cooking pans.*—There are six. They are shown in the longitudinal section. They might all with advantage be provided with steamers for boiling vegetables, the lids being fitted with small saucepans, an illustration of which is afforded in *Plate* XXI. copied from a catalogue of Gates, Haywood and Co. The covers of all the saucepans and other pots should be of tinned iron or block tin, doubled, with a vacuity between of one inch to prevent escape of heat. *The Oven.*—Five out of six of the sides of the oven-box are brought into direct contact with the heated air from the fire, and the flues surrounding the oven are encased in thick brickwork. The oven has two sliding shelves of open bar work, 9 inches apart, with a copper tray the size of the bottom for holding gravy. Large flat pie dishes of block tin should also be placed on the grated shelves, so that pies sufficient to feed some 12 men may be baked. It will be observed that the oven-box has numerous dampers to regulate its temperature, and to vary the conditions under which the food placed in it is cooked. For example, the oven is turned into a roasting apparatus by opening the top and bottom valves in the two doors, to allow of the escape of steam, and the entrance of cold air, in order to produce a continuous current of hot air.

The Erection of the Kitchener.—In building up these ranges, certain points need attention. Their efficiency greatly depends on their being properly fitted up. The bricks used in the outer casing should be hard and well burned. The inner casing should be formed of the very best firebricks, gauged in the levelled parts, and laid with close joints. So few are needed, that they might be procured from England. Soapstone will do as well. The exterior of all the brickwork should be carefully pointed, and it, and the whole kitchen should be periodically whitewashed. No plaster should be used anywhere; it cracks with the heat, and gets knocked about by the cooks. The mortar should be composed of four parts by measure of clay, four parts of well burnt brick dust, and one part of quick lime. The mortar joints should be as thin as possible. All the iron

should be wrought: no cast-iron should be used anywhere; when heated and cold liquids are splashed over it, it is very apt to crack, and heated cast-iron gives off a gas more or less hurtful, according to the amount of heat the iron has attained. The flue in the chimney shaft should be 12 × 12 inches, or 12 × 8 inches, or 9 × 9 inches, as most convenient, and every care should be taken that it is nowhere contracted, otherwise the strength of the draught will be reduced, and consequently the heating power of the range. The kitchener should be built in such a position in the room, that easy access may be had to every part of it. The kitchen should be well lighted, to allow of the food being properly looked into, and it should have plenty of ventilation.

Its daily service.—All the ironwork should be daily rubbed very clean, and certain parts of it should be polished with black-lead. The chimney and range flue should be frequently cleared of soot. The boiler should be periodically emptied and thoroughly cleansed. Water generally deposits, under the action of heat, a crust which soon prevents the proper circulation of the hot water, causes corrosion of the metal, and premature decay of the boiler with much waste of fuel.* The firewood should be cut up into small pieces of short length, so as not to injure the somewhat contracted grate, and in order that the combustion of the fuel may be more perfect. The results obtained with these kitcheners are more satisfactory if a strict and intelligent supervision over the native cooks is exercised. The cooks are apt to cram the grate with an excessive quantity of firewood, and then to jam the door, forcing the wood up against the brickwork at the back of the furnace. To please the soldiers, they cook a number of small separate dishes, one for each individual, and thus litter the cooking hearth with numberless extraneous pots and pans. They have been known to stop up the flue at the entrance to the oven, so as to obtain an unnecessarily greater heat on the cooking hearth, and to place damp clothes in the oven to be dried!

Count Rumford, who was the first to scientifically investigate the principles of cookery, published, in 1799, his views on the subject. Subsequent experience has abundantly proved their correctness, although in practice generally they do not seem to be sufficiently attended to. The Duff's Kitchener in many respects approximates closely to the maxims laid down by the Count. It is unlike them in the following particulars:—

1. Duff's Kitchener performs all its functions with a single closed fire;

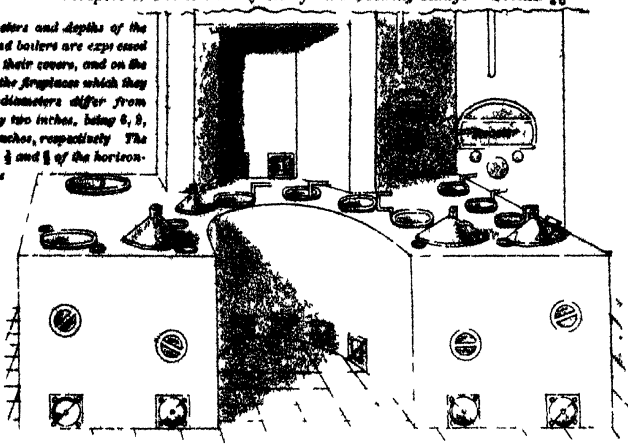
* Gervase Wheeler's "Choice of a Dwelling," 1872, page 228.

DUFF'S KITCHENER FOR BRITISH TROOPS.

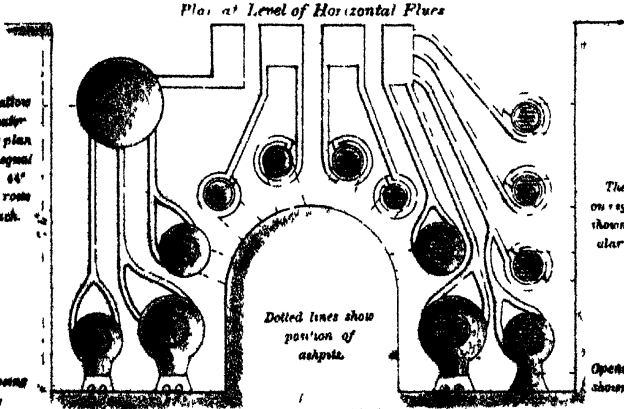
Perspective Front view of an Improved Barrack Kitchener. Height of Hot Plate 34 inch. Length 7 Hot Plate 61 inches.

RUMFORD'S KITCHENER ERECTED AT MUNICH

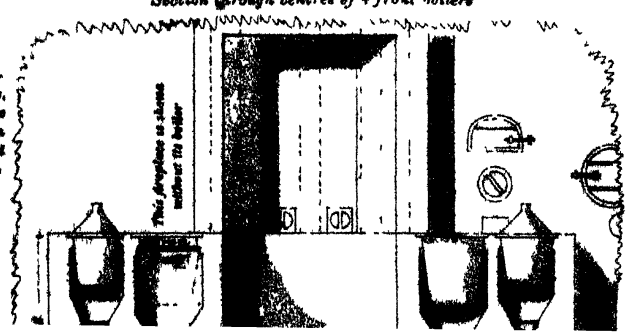
Perspective Front View of Rumford's Cooking Range — SCALE $\frac{1}{20}$



Plan at Level of Horizontal Flues



Section through centres of 4 front boilers



but Count Rumford insists that each boiler, kettle, and stewpan should have its own separate closed fireplace, with grate and ashpit, and channel to the chimney flue, with a closed registered door to each ashpit, and a damper to each smoke channel, in order to regulate the admission of air and consequent consumption of fuel.

2. The hearth or cooking table of Duff's Kitchener is of iron instead of being of firebrick, as Count Rumford recommends.
3. Count Rumford's stewpans, &c., instead of being placed on the top of the hearth, as in Duff's Kitchener, are sunk in the cooking table and surrounded with brickwork, so as to be protected from direct contact with the cold atmospheric air.*

Plate XXII. illustrates one of Count Rumford's Kitcheners which was built for a nobleman of Munich, who entertained largely. It worked satisfactorily for many years. Although the principles which it embodies are doubtless correct, it may be questioned whether it is so serviceable as Duff's Kitchener in cooking for a large number of British Troops. It is constructed on the principle of slow cooking, whereas Duff's range cooks rapidly. Its brickhearth would probably suffer from usage, and its sunken stewpans might be inconvenient to handle. It seems in short too elaborate for careless native cooks.

It may perhaps be useful in conclusion to give the four following principles which Count Rumford lays down on the subject of cooking:—

i. Meat may be boiled, or in other words dressed, in hot water, not exceeding 209° Fahr.
ii. When the water is heated so as to throw off a great deal of steam, an immense quantity of heat is wasted without the meat being better dressed; and a great proportion of the finer and more rich and savoury particles of the food are also carried off at the same time, and lost.
iii. The processes both of boiling and stewing are carried on to greater advantage when they proceed slowly, and at a low temperature, than when they are conducted rapidly, and at a high temperature.
iv. These boilers or stewpans, of wrought-iron or copper, become sooner heated, are less injured by the fire, and last longer than thick boilers of cast-iron, &c.

OOTACAMUND,
1st February, 1875. J. L. L. M.

* Loudon's "Farm and Village Architecture," 1869, page 709.

No. CLV.

BAHAWALPUR ARTIFICIAL HYDRAULIC CEMENT.

Memorandum by JOHN W. BARNS, ESQ., *M. Inst., C.E., Superintendent of Canal Irrigation, Bahawalpur State.*

IN the discussion now going on about the fitting kind of materials, &c., for mortar for different kinds of masonry works, there seems to be an absence of what I may term *practical information* on the subject derived from actual experience, as contrasted with with what one may call *laboratory experiments*, which are often undertaken under circumstances where a degree of care is taken about every operation which in practice never occurs.

The following description will serve as an interesting and really *practical* illustration of the excellent quality of the masonry which can be built even under unfavorable circumstances, with artificial hydraulic cement made according to the method adopted at Kurrachee, and described both in the "Professional Papers of Indian Engineering," and in the "Roorkee Treatise of Civil Engineering" (3rd Ed. of Vol. I., para. 87). It will however be noticed that in the building now described the mortar was composed of *soorkee* (instead of *sand* as at Kurrachee) mixed with the artificial lime cement.

In July 1868, a sluice was built at the head of a small canal of twelve feet bottom breadth: it was built in a great hurry, and full head of water was admitted into the canal the day after the sluice had been finished.

In the absence of bricks of a superior description, we were obliged to

use the small thin bricks (obtained from a neighbouring kiln) that had been burnt by a zemindar, and they were therefore of the roughest description to be found.

The mortar used was composed of 1 part artificial hydraulic lime to 2 parts soorkee by measure. The hurry with which the sluice was constructed did not admit even of any choice being made of the bricks from which the soorkee was prepared, and we may infer that those bricks, from which the soorkee was prepared, were used which were the most easily pulverized.

The artificial hydraulic lime was prepared according to the proportions used in the Scind Public Works Department, viz., Sukkur stone lime slaked to powder, 5½ parts to 1 part by measure of freshly dug potters' clay, in fact just as described by Mr. Price, M. Inst. C.E., in No. CXLVI. of the Roorkee Professional Papers.

The cement and soorkee were ordered to be ground fine under hand mill stones, (or chukkees as the natives term them,) but the work being under superintendence of a Native Revenue Officer of a Native State, this was imperfectly done, as we may suppose.

The sluice in question has been in use for from eight to ten months every year since its first construction until now, when its demolition, for reasons not necessary to enter into, was ordered.

Although the materials used were, as described, of the roughest, the mortar joints were much thicker than ever seen where well moulded bricks are used; but I cannot better describe the solidity of the structure than by quoting a report thereon made at the time:—

"The structure is so solid that it is only by the aid of crowbars and pickaxes that it can be pulled to pieces, and so great is the hardness and adhesive power of the artificial hydraulic cement used, that even with those tools scarcely a brick can be taken out whole, and under the action of the pickaxes the bricks do not part at the masonry joints, but are chipped off in small flakes. The English Contractor, Mr. John Robson, and his partner, happened to be passing when I was inspecting this work, and observing the small amount of work done by the coolies employed, suggested that the easiest and cheapest method of demolishing it would be to blow it up. I timed the work done by the coolies per day, and found that it averaged eight cubic feet per man."

J. W. B.

No. CLVI.

CROSS SECTIONS FOR ESCAPE CHANNELS.

Note on the Cross Sections suitable for Escape Channels to which only a moderate rate of fall can be given. By Col. P.O'Connell, R.E., *Offg. Chief Engineer, Irrigation Works, Punjab.*

My attention was drawn to the consideration of this question by observing the state of the Rer Escape of the Western Jumna Canal. The bed of this escape channel is obstructed by silt and tall grass, to such an extent as to be almost blocked up owing to the want of scour. The velocity and consequently the scouring power of the water in the channel is small owing to three causes:—

1*st.* The supply of water is intermittent instead of being, like that in the Western Jumna Canal itself, permanent.

2*nd.* The rate of the fall of the bed is small.

3*rd.* The cross section is broad and shallow, and the hydraulic mean depth is consequently small, even when the supply of a water is a maximum.

The first of these causes will always exist, it being the duty of an escape channel to carry off a portion of (or an occasionally superabundant supply from) the Main Canal. The second cause can only be partly removed by choosing a better line for the escape. The third should in this, and in every other case, where a rapid rate of fall cannot be obtained, be, as far as possible, removed by giving the cross section of the water such proportions of breadth and depth as shall make the velocity of discharge a maximum. It is the object of the following investigation to discover what these proportions are when the maximum discharge of the escape and its rate of fall are known.

If the side slopes be 1·5 to 1 $\left(i.\ e.,\ \frac{1\cdot5 \text{ horizontal}}{1 \text{ vertical}}\right)$

b = bed width in feet.

d = depth of water in feet.

f = fall of channel in 5,000 feet in feet.

A = area of cross section in square feet.

R = hydraulic mean depth in feet.
V = mean velocity in feet per second.
D = the discharge in cubic feet per second.

Then $D = AV$.

$$A = \left(b + \tfrac{3}{2}d\right)d$$

$$R = \frac{A}{b + 3{\cdot}606d}$$

$$V = \frac{R\sqrt{f}}{\sqrt{1{\cdot}75 + {\cdot}42665R}}$$

Substituting for R its value as given above, we have—

$$V = \frac{\frac{A\sqrt{f}}{b + 3{\cdot}606d}}{\sqrt{1{\cdot}75 + \frac{{\cdot}42665A}{b + 3{\cdot}606d}}} = \frac{\frac{A\sqrt{f}}{\frac{A}{d} + 2{\cdot}106d}}{\sqrt{1{\cdot}75 + \frac{{\cdot}42665A}{\frac{A}{d} + 2{\cdot}106d}}}$$

$$= \frac{\sqrt{f}}{\sqrt{1{\cdot}75\left(\frac{1}{d} + 2{\cdot}106\frac{d}{A}\right)^2 + {\cdot}42665\left(\frac{1}{d} + 2{\cdot}106\frac{d}{A}\right)}}$$

An expression which is a maximum when the denominator of the fraction is a minimum, which it is when $\frac{1}{d} + 2{\cdot}106\frac{d}{A}$ is a minimum. This latter expression is a minimum when its first differential co-efficient—

$\frac{1}{d^2} + 2{\cdot}106 \times \frac{1}{A} = 0.$

That is when $A = 2{\cdot}106d^2$.

Substituting this value of A in the expressions for D and V already obtained, we have—

$$D = AV = \frac{2{\cdot}106d^2\sqrt{f}}{\sqrt{\frac{7}{d^2} + \frac{{\cdot}8533}{d}}}$$

$$\therefore d^5 = \left\{\frac{7}{2{\cdot}106}^2 + \frac{{\cdot}8533}{2{\cdot}106}^1 d\right\}\frac{D^2}{f}.$$

$$\text{or } d^5 = \left\{1{\cdot}5782 + {\cdot}1923d\right\}\frac{D^2}{f}.$$

From this expression the depth of the cross section can easily be found when the values of D (the discharge) and of f (the fall of the bed in a length of 5,000 feet) are given.

The value of A is then found from the equation $A = 2{\cdot}106d^2$.

The value of b is found from the equation $b = \frac{A}{d} - \frac{3}{2}d$.

P O'C.

No. CLVII.

PARTICULARS OF CRUSHING N. W. P. STONE SPECIMENS.

By F. Sills, Esq., *Exec. Engineer, 4th C. Division.*

Particulars of crushing 18 *specimens of stones, and* 6 *specimens of brick, forwarded to the Master of the Mint from the Government, North Western Provinces, Public Works Department, on the* 19*th March,* 1874.

Sheet No. 1.

Dated 30th January, 1875.

Mark.	No. of Specimen (Stones.)	Sizes. Length.	Sizes. Breadth.	Total superficial area.	Pressure on gauge on square inch. Crushed.	Area of Ram.	Total pressure. Crushed.	Deduct for friction, &c., 10 per cent. Crushed	Actual pressure on square inch. Crushed.	Average of crushing of each Specimen.	Average of crushing of each description.	Order of strength.	Remarks.
Pertabpore. 787	No. 1 specimen,	1½ inch	1″ × 1″	1″ sqr.	500	19·63	9,815	981	8,834				
788	Ditto	Ditto	Ditto	Ditto	490	Ditto	9,618	961	8,657	9,069			
789	Ditto	Ditto	Ditto	Ditto	550	Ditto	10,796	1,079	9,717				
790	No. 2 specimen,	Ditto	Ditto	Ditto	530	Ditto	10,403	1,040	9,363				
791	Ditto	Ditto	Ditto	Ditto	540	Ditto	10,600	1,060	9,540	9,422	9,265	2	Red sand-stone.
792	Ditto	Ditto	Ditto	Ditto	530	Ditto	10,403	1,040	9,363				
793	No. 3 specimen,	Ditto	Ditto	Ditto	540	Ditto	10,600	1,060	9,540				
794	Ditto	Ditto	Ditto	Ditto	540	Ditto	10,600	1,060	9,540	9,304			
795	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834				

MIRZAPORE.	796	No. 4 specimen,	Ditto	Ditto	Ditto	470	Ditto	9,226	922	8,304	7,773	8,617	3	Red sand-stone.
	797	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834				
	798	Ditto	Ditto	Ditto	Ditto	350	Ditto	6,870	687	6,183				
	848	No. 5 specimen,	Ditto	Ditto	Ditto	520	Ditto	10,207	1,020	9,187	9,245			
	849	Ditto	Ditto	Ditto	Ditto	530	Ditto	10,403	1,040	9,363				
	850	Ditto	Ditto	Ditto	Ditto	520	Ditto	10,207	1,020	9,187				
	799	No. 6 specimen,	Ditto	Ditto	Ditto	520	Ditto	10,207	1,020	9,187	8,834			
	800	Ditto	Ditto	Ditto	Ditto	480	Ditto	9,422	942	8,480				
	801	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834				
MARKOONDEE.	802	No. 7 specimen,	Ditto	Ditto	Ditto	460	Ditto	9,029	902	8,127	7,773	7,283	5	Ditto.
	803	Ditto	Ditto	Ditto	Ditto	480	Ditto	9,422	942	8,480				
	804	Ditto	Ditto	Ditto	Ditto	380	Ditto	7,459	745	6,714				
	805	No. 8 specimen,	Ditto	Ditto	Ditto	450	Ditto	8,833	883	7,950	8,009			
	806	Ditto	Ditto	Ditto	Ditto	450	Ditto	8,833	883	7,950				
	807	Ditto	Ditto	Ditto	Ditto	460	Ditto	9,029	902	8,127				
	808	No. 9 specimen,	Ditto	Ditto	Ditto	360	Ditto	7,066	706	6,360	6,007			
	809	Ditto	Ditto	Ditto	Ditto	300	Ditto	5,889	588	5,301				
	810	Ditto	Ditto	Ditto	Ditto	360	Ditto	7,066	706	6,360				
SHEORAJPORE.	811	No. 10 specimen,	Ditto	Ditto	Ditto	630	Ditto	12,366	1,236	11,130	11,283	9,983	1	White sand-stone.
	812	Ditto	Ditto	Ditto	Ditto	640	Ditto	12,663	1,266	11,397				
	813	Ditto	Ditto	Ditto	Ditto	641	Ditto	12,582	1,258	11,324				
	814	No. 11 specimen,	Ditto	Ditto	Ditto	440	Ditto	8,637	863	7,774	8,480			
	815	Ditto	Ditto	Ditto	Ditto	550	Ditto	10,796	1,079	9,717				
	816	Ditto	Ditto	Ditto	Ditto	450	Ditto	8,833	883	7,950				
	746	No. 12 specimen,	Ditto	Ditto	Ditto	550	Ditto	10,796	1,079	9,717	10,187			
	747	Ditto	Ditto	Ditto	Ditto	560	Ditto	10,992	1,099	9,893				
	748	Ditto	Ditto	Ditto	Ditto	620	Ditto	12,170	1,217	10,953				

Mark.	No. of Specimen (Stones.)	Sizes. Length.	Sizes. Breadth.	Total superficial area.	Pressure on gauge on square inch. Crushed.	Area of Ram.	Total Pressure. Crushed.	Deduct for friction, &c., 10 per cent. Crushed.	Actual pressure on square inch. Crushed.	Average of crushing of each Specimen.	Average of crushing of each description.	Order of strength	Remarks.
MIRZAPORE.													
817	No. 13 specimen,	1½ inch	1" × 1"	1" sqr.	450	19·63	8,833	883	7,950				
818	Ditto	Ditto	Ditto	Ditto	450	Ditto	8,833	883	7,950	7,950			
819	Ditto	Ditto	Ditto	Ditto	450	Ditto	8,833	883	7,950				
820	No. 14 specimen,	Ditto	Ditto	Ditto	430	Ditto	8,440	844	7,596				
821	Ditto	Ditto	Ditto	Ditto	490	Ditto	9,618	961	8,657	7,949	7,144	6	Yellow sandstone.
822	Ditto	Ditto	Ditto	Ditto	430	Ditto	8,440	844	7,596				
749	No. 15 specimen,	Ditto	Ditto	Ditto	300	Ditto	5,889	588	5,301				
750	Ditto	Ditto	Ditto	Ditto	290	Ditto	5,692	569	5,123	5,535			
751	Ditto	Ditto	Ditto	Ditto	350	Ditto	6,870	687	6,183				
752	No. 16 specimen,	Ditto	Ditto	Ditto	400	Ditto	7,852	785	7,067				
753	Ditto	Ditto	Ditto	Ditto	360	Ditto	7,066	706	6,360	6,478			
754	Ditto	Ditto	Ditto	Ditto	340	Ditto	6,674	667	6,007				
755	No. 17 specimen,	Ditto	Ditto	Ditto	380	Ditto	7,459	745	6,714				
756	Ditto	Ditto	Ditto	Ditto	390	Ditto	7,655	765	6,890	7,126	7,418	4	Yellow sandstone, different grain.
757	Ditto	Ditto	Ditto	Ditto	440	Ditto	8,637	863	7,774				
823	No. 18 specimen,	Ditto	Ditto	Ditto	510	Ditto	10,011	1,001	9,010				
824	Ditto	Ditto	Ditto	Ditto	510	Ditto	10,011	1,001	9,010	8,651			
825	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834				

Mark.	No. of Specimens, (brick, stones.)	Sizes. Length.	Sizes. Breadth.	Total superficial area.	Pressure on gauge on square inch. Crushed.	Area of Ram.	Total pressure. Crushed.	Deduct for friction, &c., 10 per cent. Crushed.	Actual pressure on square inch. Crushed.	Average of crushing of each Specimen.	No. of days in water.	Average of crushing of similar specimen, *see* Sheet No. 1.	Remarks.
758	A. P. D. Brick light,	1½ inch	1″ × 1″	1″ sqr.	230	19·63	4,514·9	451	4,063				
759	Ditto	Ditto	Ditto	Ditto	240	Ditto	4,711·2	471	4,240	4,122	Nil	...	Good close grained brick.
760	Ditto	Ditto	Ditto	Ditto	230	Ditto	4,514·9	451	4,063				
761	A. P. D. Brick,	Ditto	Ditto	Ditto	300	Ditto	5,889	588	5,301				
762	Ditto	Ditto	Ditto	Ditto	250	Ditto	4,907·5	490	4,417	4,240	Nil	...	Ditto.
763	Ditto	Ditto	Ditto	Ditto	170	Ditto	3,337·1	333	3,004				
764	Ditto	Ditto	Ditto	Ditto	170	Ditto	3,337·1	333	3,004				
765	Ditto	Ditto	Ditto	Ditto	270	Ditto	5,300·1	530	4,770	4,181	Nil	...	Ditto.
766	Ditto	Ditto	Ditto	Ditto	270	Ditto	5,300·1	530	4,770				
767	O. R. R. Brick,	Ditto	Ditto	Ditto	150	Ditto	2,944·5	294	2,650				
768	Ditto	Ditto	Ditto	Ditto	190	Ditto	3,729·7	372	3,357	3,062	Nil	...	Good close grained brick, light color.
769	Ditto	Ditto	Ditto	Ditto	180	Ditto	3,533·4	353	3,180				
770	Ditto	Ditto	Ditto	Ditto	150	Ditto	2,944·5	294	2,650				
771	Ditto	Ditto	Ditto	Ditto	220	Ditto	4,318·6	431	3,887	3,357	Nil	...	Good close grained brick.
772	Ditto	Ditto	Ditto	Ditto	200	Ditto	3,926	392	3,534				
773	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834				
774	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834	9,128	Nil	...	Very close grained hard, dark color.
775	Ditto	Ditto	Ditto	Ditto	550	Ditto	10,796·5	1,079	9,717				Very well burnt.
Pettah-pore. 830	No. 1 specimen,	Ditto	Ditto	Ditto	460	Ditto	9,029·8	902	8,127		6 days		*See* Nos. 787, 788, 789.
831	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,833	8,362	Ditto	9,069	Red sand-stone.
832	Ditto	Ditto	Ditto	Ditto	460	Ditto	9,029 8	902	8,127		Ditto		
Mirza-pore. 833	No. 6 specimen,	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834		Ditto		*See* Nos. 799, 800, 801.
834	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834	8,834	Ditto	8,834	Red sand-stone.
835	Ditto	Ditto	Ditto	Ditto	500	Ditto	9,815	981	8,834		Ditto		

Mark.	No. of Specimens, (brick, stones.)	Sizes. Length.	Sizes. Breadth.	Total superficial area.	Pressure on gauge on square inch. Crushed.	Area of Ram.	Total pressure. Crushed.	Deduct for friction, &c., 10 per cent. Crushed.	Actual pressure on square inch. Crushed.	Average of crushing of each Specimen.	No. of days in water.	Average of crushing of similar specimen, *see* Sheet No. 1.	Remarks.
SHONAJ-MARKOONDEE. 836	No. 7 specimen,	1½ inch	1" × 1"	1" sqr.	430	19·63	8,440 9	844	7,576				
837	Ditto	Ditto	Ditto	Ditto	390	Ditto	7,655·7	765	6,890	7,295	7 days	7,773	*See* Nos. 802, 803, 804. Red sandstone.
838	Ditto	Ditto	Ditto	Ditto	420	Ditto	8,244 6	824	7,420				
SHONAJ-PORE. 839	No. 10 specimen,	Ditto	Ditto	Ditto	620	Ditto	12,170·6	1,217	10,953				
840	Ditto	Ditto	Ditto	Ditto	530	Ditto	10,403·9	1,040	9,363	10,600	Ditto	11,283	*See* Nos. 811, 812, 813. White sandstone.
841	Ditto	Ditto	Ditto	Ditto	650	Ditto	12,759 5	1,275	11,483				
MIRZA-PORE. 842	No. 14 specimen,	Ditto	Ditto	Ditto	420	Ditto	8,244·6	824	7,420				
843	Ditto	Ditto	Ditto	Ditto	400	Ditto	7.852	785	7,067	6,890	Ditto	7,949	*See* Nos. 820, 821, 822. Yellow sandstone.
844	Ditto	Ditto	Ditto	Ditto	350	Ditto	6,870 5	687	6,183				
MIRZA-PORE. 845	No. 17 specimen,	Ditto	Ditto	Ditto	400	Ditto	7,852	785	7,067				
846	Ditto	Ditto	Ditto	Ditto	390	Ditto	7,655·9	765	6,890	6,949	9 days	7,126	*See* Nos. 755, 756, 757. Yellow sandstone (different grain).
847	Ditto	Ditto	Ditto	Ditto	390	Ditto	7,655·9	765	6,890				

1. These specimens of stones and bricks have been tried in a small hydraulic press worked by a force pump, and the pressure ascertained by a Bourdon's pressure gauge.
2. The specimens were fully crushed.
3. To give each specimen a fair chance arising from any inequality on the top or bottom of it, whilst in the hydraulic press, thin pieces of teak wood were placed on the top and bottom of each sample.
4. All specimens tried were of full dimensions.
5. Ten per cent. has been taken off the crushing weight for friction, (refer to "Rankine's Steam Engine," page 131.)
6. For comparison of crushing of English stones, refer to "Rankine's Useful Rules and Tables," 1873, page 203.
7. " " " bricks, refer to paper of "Architectural Association of London", 8th January, 1875, result of 6 experiments by Kirkaldy's hydraulic press.

F. S.

No. CLVIII.

EARTHWORK EXPERIMENTS ON THE SIRHIND CANAL.

[*Vide* Plates XXIII. to XXIX.].

Reports by Supdg. and Executive Engineers, Sirhind Canal, and Note by Chief Engineer, Punjab Irrigation Department.

Reports by J. D. DERBY, ESQ., *Executive Engineer, 2nd Division, Sirhind Canal.*

Dated Khirri, 19th June, 1873.

Experiment No. 1. Barrow System.—The rates at which work has been done here by the coolie and basket, have ranged from Rs. 2-4 per 1,000 for 3 feet depth and a lead of about 150 feet, to Rs. 5-8 for the lowest lift of 10 feet in 35 feet deep cutting, with a horizontal mean lead of about 200 feet.

It was to compete with these rates and speed of working, that experiments were made with various machines.

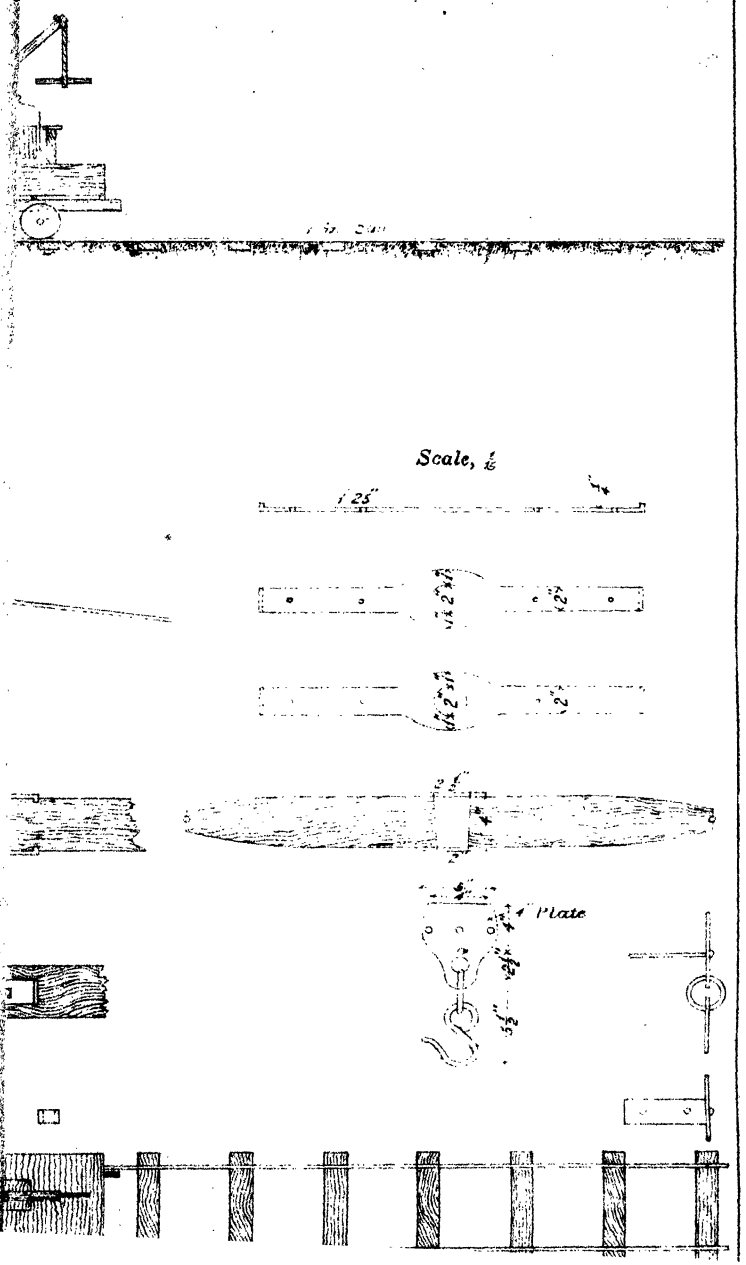
The first experiment was with wheel-barrows (in a cutting of 13 feet depth, and height of spoil about 10 feet), by means of an endless rope passing round two grooved wheels, 4 feet diameter, set in an inclined position at the top of, and foot of, a slope of 3 to 1; the rope had swells or knots at every 6 feet, against which a fork attached to the back of the wheel-barrow on one side of it was pushed by a man descending with the barrow empty, and thus raised a full barrow similarly attached to the knotted rope, only that the knot was on the opposite side of the fork to that on the empty: the man with the full barrow merely supporting and guiding it.

This plan was found to work admirably with strong men capable of

managing a wheel-barrow; but it was necessary to have a hard road for the wheels to run on, and the cost of planks for this purpose was too great to allow of it being extensively used, and it required some skill to keep the barrow wheel on the path. It was therefore abandoned; but I have since had wheel-barrows fitted with iron grooved-wheels, which ran on a rail of bar-iron 2 × ½ inch, kept vertical by being keyed at every 6 feet by a wooden wedge into a short sleeper. The wheel is fixed slightly askew, to keep it parallel to the rail, while the man walks at the side; with this arrangement, I believe, the endless rope barrow lift, as described above, would work well for depths not exceeding 23 feet; but beyond this the length of rope becomes difficult to manage. Barrows with grooved-wheels were used for some months in conjunction with another lift, when the horizontal lead was about 150 feet, and they worked well; the men soon getting into the difficulty of pushing the barrow from one side, and not the centre as it should be; and this difficulty is the principal objection to the grooved-wheel, but not a condemning fault where wheel-barrows could be used.

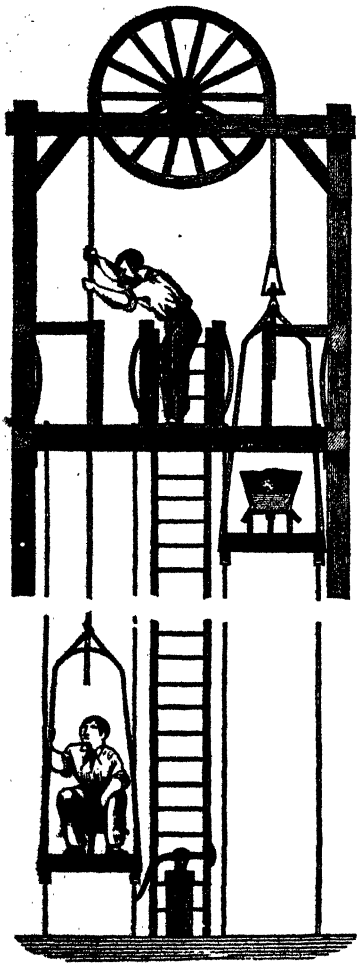
The endless rope barrow lift gave economical results while working; but I consider it impracticable for extensive use, on account of skill required in fixing and re-fixing, as the excavation progresses, and the large quantity of plant required for such excavation as a canal channel.

Experiment No. 2. Revolving Beam System.—The next experiment tried was a "revolving beam," fixed at an angle of 45°, revolving on a pivot (attached to a post sunk in the slope, at an angle of 45° from the vertical), so that when one end was down in the excavation, the other was above the spoil. To hooks attached to the ends of the beam were suspended 2-cubic-feet skips (*see Plate* XXIII.). Projecting 3 feet beyond the two ends of this beam were smaller pieces, (which might be called sprits,) so that a rope suspended from their extremites hung clear of the skips (to these ropes, 1 foot 6 inches long, were attached rounded sticks), enabling a man to sit on the upper one with the rope between his legs; thus a man weighing about 12 stone would, on a 22-feet beam, more than counterpoise the two cubic feet of sand in the box at the other end; and on the beam being pushed to one side, so that the weights hung to one side of its centre of gravity, the greater combined weight of the man and empty box, descended and raised the full box of sand, which was then capsized into a wagon or wheel-barrow to carry it to tip; the


Scale, ½
1 Plate

man that descended dismounts from the rope, and walks up the slope; the empty box just taken down being replaced by a full one.

In this manner, a man is supposed to be able to perform more work than by any other mode of exertion (*see* Rankine on the Steam Engine, page 85); for when he ascends the slope, he stores energy to an amount equal to the product of his weight into the vertical height of ascent, which energy is expended when he descends on one arm, and raises the load on the other. It might not be out of place here to state that a different application of this principle was made by Captain Coignet, of the French Engineers, in earth excavation, 40 feet deep, at Versailles; of which the following is a description (and sketch), extracted from "Lardner's Mechanics":—"If two baskets be connected by a rope which passes over a pulley at the level to which heavy matter is to be raised, the length of the rope being such, that when one of the baskets is brought up to that level, the other shall have descended to the level from which the heavy matter is to be elevated, the lower basket being charged, let one or more men get into the upper basket, so as to give it, by their weight, a sufficient preponderance to make it descend, drawing up the lower basket with its load. When the latter has been brought up and discharged at the upper level, the men leave the lower basket and charge it, when men at the upper level get into the upper basket, and again bring up the lower as



before. Meanwhile, the men who had previously gone down, again ascend to the upper level by a ladder or staircase. In this manner, the work may be continued without any intermission, the labor of the men consisting exclusively in elevating the weights of their own bodies while ascending the ladder or staircase.

"It is found by experiments, conducted upon a large scale, that men working in this manner for eight hours a day, can produce in each day an effect equivalent to 2,000,000 lbs. raised one foot.

"The great advantage obtained by this mode of applying animal force will be apparent, when it is stated that the man who can thus produce an effect of two millions of pounds, could not produce, in working at a windlass, a greater effect than a million and a quarter; while, if he acted upon a pile-engine, he would produce an effect of only three quarters of a million.

"An apparatus such as that here described, is represented in the figure on preceding page. It was employed in making the earthworks at Vincennes, near Paris, and was found to be attended with great economy."

This system might possibly be applicable to this heavy excavation in certain places requiring great despatch; but the same objection to its use on such an extended scale as 40 miles of digging, is the multiplication of plant and skilled supervision, which, unless required elsewhere on completion of the work on which employed, and the cost of plant chargeable against the excavation, would probably bring the rate up to what it would be by coolie and basket.

This "revolving beam," as stated above, was first used to raise skips, which were conveyed from the face to the foot of lift on a hand-barrow or wagon, and hooked on to the beam; and as long as it was limited to a depth requiring only one beam, the work done compared favorably with excavation by basket, and still more so, when wheel-barrows were substituted for the skips, thus avoiding the difficulty of loading and carrying the skips, which were not suitable, being deep and narrow; but, when a lower lift was tried, necessitating a second revolving beam from which the skip had to be transferred to the upper, the movements became too numerous, and its extensive use was out of the question. But the conclusion arrived at was, that for raising water from depth (about 15 feet), for which one beam could be constructed economically, and where the beam would not require to be constantly moved, this mode of applying human

labor is the most economical one, a man being able to work at the rate of 2,000,000 feet pounds raised per day, which I have done with ease myself.

Experiment No. 3. 5-Cubic-Feet Wagon System (*Plate* XXIV.) —The next and last experiment tried for applying human labor to raise material from excavation, was similar to the first, inasmuch as the inclined plane and horizontal wheel round which the rope passed were used, and it has been successful in proportion to the diminished skill required for performing the various operations. Thus, the wheel-barrow requiring strength and practice to propel and guide it, was replaced by 5-cubic-feet four-wheeled wagons running on rails; and the endless rope requiring careful adjustment, replaced by a single rope with hooks at either end.

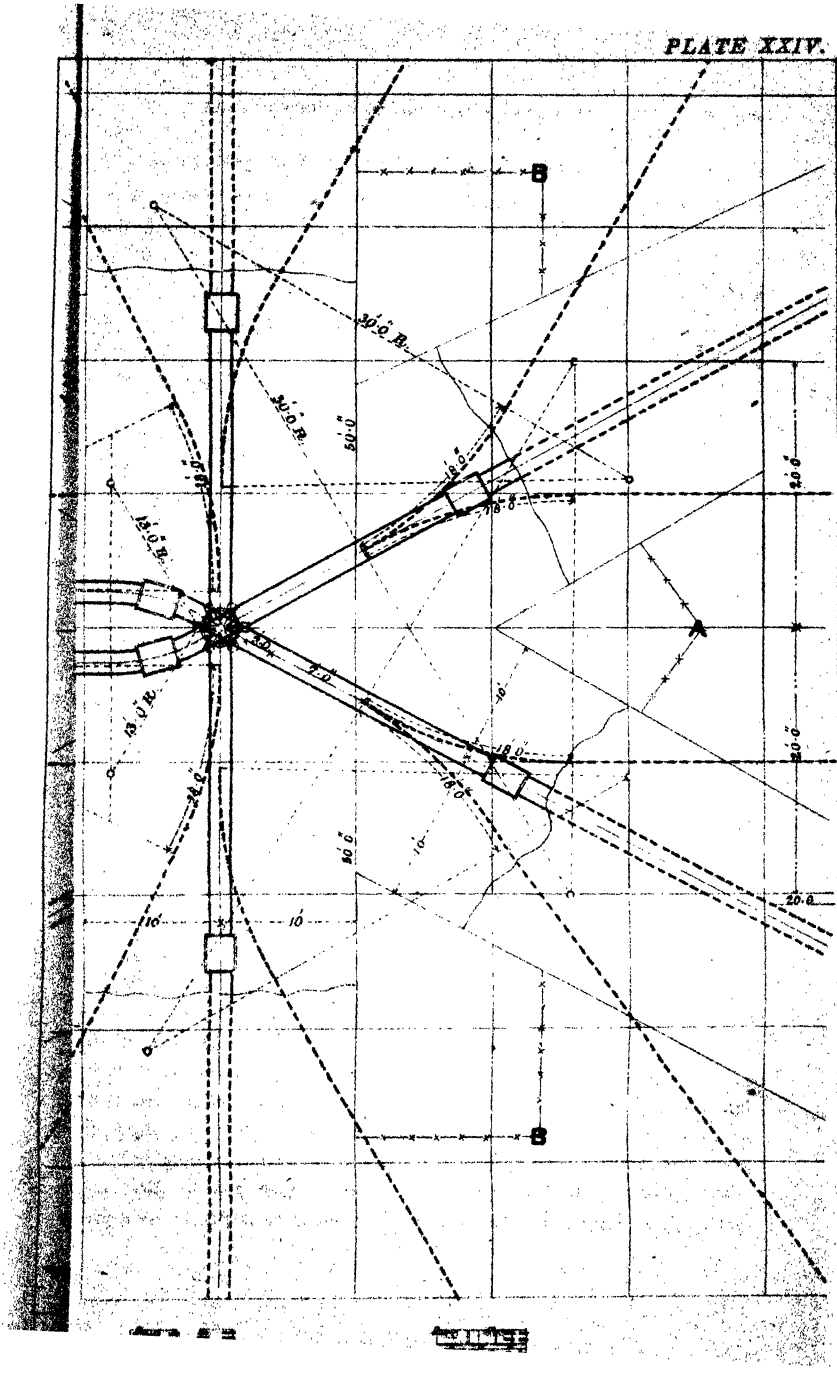
It is self-evident, that the great point to aim at to economise power is, that the weight of the carriage for the excavated material (which always bears a large proportion to its load), shall be counter-balanced by the descending empty, leaving merely the weight of the load and the friction of the axles to be overcome; and the most convenient mode of applying the necessary power was found to be men pushing. Three men only can safely and conveniently apply their power to these 5-cubic-feet wagons, (a large number of them being already made for use in a different manner,) and it was found that a slope of 3 to 1 was necessary to reduce the gravity to be overcome within their power, and this degree of slope is also the greatest that can be conveniently given with regard to the section of canal: so, considering that the slope is limited to 3 to 1, and that if it was desired to raise a greater load, more power would have to be applied, which would necessitate a different form of wagon, unless the extra man or men got into the wagon, which is dangerous in case of a wagon breaking away, and that all the parts connected with the hauling would have to be increased in strength. I conclude that the present wagon of 5-cubic-feet capacity is of the best size, and that the three men pushing it down is the best mode of applying the power, one man with the rope between his legs, and the other two on either side, all three leaning on the wagon, so that they have only to exert muscular power in excess of their weight thus thrown on to it. This mode of applying man's power, does not produce such a large result, as when the man's weight only in descending raises the load, due doubtless to his having to exert muscular power, both in descending and ascending. The lift at Rájpur is 23 feet, raising 600 wagons of 540 lbs. each, and nine men raise this quantity,

so $\frac{23 \times 600 \times 540}{9} = 828{,}000$ feet lbs. per day, and at Khirri with a lift of 53 feet, raising 570 wagons of 540 lbs., each raised by 15 men, giving $\frac{53 \times 570 \times 540}{15} = 1{,}087{,}422$ feet lbs. Of course the men are lighter than European workmen, who with Coignet's machine, effect 2,000,000 feet lbs.; but still I hope to get a higher result.

But the means for raising the load, viz., the inclined plane on the ground, must give it the preference to Captain Coignet's plan, necessitating an expensive tower difficult to fix and remove, and more liable to serious accidents.

This mode of raising having been decided on, the next point was to have some simple means of receiving and distributing the wagons. Four faces in excavation is the least number that could ensure an uninterrupted supply of wagons for nine men raising, and these were brought on radiating lines to the foot of the slope, where an iron-plate 8 × 4 feet received the ends of the rails from slope and excavation faces, they having as short a bearing as possible, about 2 inches, so as to leave as much of the clear plate as possible; the ends of the rails had short inclined pieces let into them to facilitate the wagon rising on to them. The full wagon can then easily be turned with the aid of a lever as required, to shift them from one line to another; the empties being turned without the aid of a lever, merely by raising the hind wheels by hand, and turning the wagon on the front wheels; this was greatly facilitated by having one of the front wheels loose on its axle, but their being loose was found troublesome, due to the inaccuracy in the construction of the wagons, and they constantly came off the line, so no more wheels were loosened, although those loosened are still used.

This plate, though admirable for its simplicity, and being easily procured, is a barbarous mode of effecting the desired end (of turning the wagons), and pulling the wagons round with a lever, racks them greatly, so that their repairs were very heavy; consequently a 6-throw turn-table was designed; the small gauge (1 foot 6 inches) of the wagons enabling it to be of such a size as to be conveniently of cast-iron, the great importance of which is evident when it is remembered that, to construct a turn-table properly, some thought and skill is necessary, requiring expensive workpeople and appliances; but with a casting it only requires that a pattern be carefully made, and the core is then stereotyped in each casting; too great importance cannot be attached to this fact; and, far-


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ther, the cost of making one of wrought-iron, (wood being out of the question, from its liability to be affected by the weather,) would be at least four times that of cast, even if the skilled labor were available. The cost of one is Rs. 50. The effectiveness of this 6-throw turn-table will be best shown, by stating that 10 wagons (five fulls and five empties) can be turned in one minute; the fulls being tipped and then returned (of course the tip heads were quite close in this case), so that, provided the wagons could be supplied and taken away, it could supply, 3,000 full wagons in a day of 10 hours; and this suggests the idea of a small steam hoist to raise the wagons, since with men, 1,000 is the maximum that could be expected; but I have made the men work at the rate of 1,200; but up to the present 600 is the number raised daily—only on one day 800 being raised from 25 feet excavation, to a spoil 15 feet high, with 12 *picked men* (at Khirri).

The drawings on *Plate* XXIV. will further explain the arrangements; it being only necessary to say that the fulls always ascend the same line, and the empties descend the other; this being effected by changing the hook that has just come up, attached to a full to the other side to be hooked on to an empty. I consider this a vital point in the system, since it enables a full and empty to be always at the foot and top of slope respectively, and thus cause no interruption. With an endless rope, and the wheel set in motion by steam or other power, this would, of course, be the case, and the attaching the wagons to the moving rope could easily be effected without causing any jerk to the wagons, by giving them the same velocity on the level as that of the rope, and on reaching the rope attaching themselves by means of a self-acting catch.

The number of wagons required with the ordinary lead that the section of this canal gives, and where the earth is tipped opposite where excavated, is twelve,—four being required at face of excavation, four tipping, and four in transit, and this is the number also used at Ráipur hill, but the extra lead due to this unusual case is overcome by tipping the 5-cubic-feet wagons into 25-cubic-feet ones, which stand on a lower level, and thus carry away six small wagon loads at a time, which simplifies the tipping, and obviates the necessity of increasing the number of small wagons, with other self-evident advantages.

The system of excavating and spreading on spoil when using the 6-throw turn-table, is shown in *Plate* XXIV., requiring four sets of curved rails above and below, all the rest being straight.

The wheel at top of slope should be five feet diameter, with a broad shallow groove. The first wheel used here, was that of a country cart, 4 feet diameter, with a groove cut in it, and the cart axle formed the pivot for it to turn on; and nothing better can be desired if only the wheel is increased to 5 feet diameter to give sufficient space between the ascending and descending wagons, or the inside man pushing down would come in contact with the ascending wagon.

The rope used is 1 inch circumference wire rope. The number of men employed on a 53-feet lift (being a slope of 160 feet long) to raise 600 wagons, are five sets of three, and the time ordinarily occupied in raising a wagon is half a minute, and ten seconds in changing the rope; but allowing for stoppages, the average is one wagon raised per minute, and this is probably the limit at this depth. These men receive only 3½ annas, and are consequently not picked; but when 4 annas are given, a stronger set of men are obtained, and more than 600 would be raised; six men are required for filling and bringing and taking away the wagons in pit, and two at head clearing the wagons, they also coming to turn-tables for, and returning their wagons; one man is employed at each turn-table; and when the lead from the bank head is 50 feet, a boy is required for running the wagons to the turn-table: in the present instance two boys are used, the lead being 100 feet; there are, besides, one man to receive the wagon as it reaches the top of slope, and pass the hook over to the men waiting with the empty about to descend, and one boy at the foot of slope to hook on to fulls; one platelayer is sufficient with a boy to put in additional lengths of rail as the work progresses, and one mate to look after the whole. Or collected—

				As.	P.
15	men raising, at 3½ annas each, ...	=		52	6
6	„ getting and filling sand, at 3½ annas each, ...	=		21	0
2	„ at turn-tables above and below, at 3½ annas each,	=		7	0
2	„ tipping, at 3½ annas each, ...	=		7	0
1	man receiving and transferring hook to empty, at 3½ annas,	=		3	6
26					
1	boy at bottom hooking on, at 3 annas, ...	=		3	0
2	boys running on spoil, at 3 annas each, ...	=		6	0
1	platelayer, at 4 annas, ...	=		4	0
1	„ boy, at 3 annas, ...	=		3	0
1	mate, at 4 annas, ...	=		4	0
				111	0
	Add for grease, ...			4	0
				115	0

for 600 wagons containing 4½ cubic feet each, or 2,700 cubic feet for 115 annas, from an excavation 35 feet deep, and spoil 15 feet high, or Rs. 2-12-8; add for plant 12 annas = Rs. 3-8-8,* which costs by coolie labor Rs. 5. On a 22-feet lift at Ráipur, the working rate is Rs. 2-8† per 1,000, with a lead of 650 feet, which is got over by using 25-cubic-feet wagons, which take six small wagon loads. This line is to take the earth from four small wagon lifts, and tip it at the nearest point, which, as stated above, is 650 feet; to do this by basket work would, according to petty contract rates, cost Rs. 7, and the lowest lift or 50 feet, would be Rs. 9, which, judging from the deep lift at Khirri, will not cost more than Rs. 3-8. There are, in the excavation of this hill (which allows of the spoil being thrown on one side only, thus giving excessive leads), six other small lifts, each having a 25-cubic-feet wagon run to overcome the extra lead. Each road will have to take out about seven lakhs, and the lowest lift will be 50 feet. The leads of these six are only 210 feet, and would cost, at contract rates, for the upper lift, Rs. 4-2 per 1,000, and the lowest, Rs. 7-5 per 1,000, and, with wagons, the mean rate will be Rs. 3 to Rs. 3-8. To these rates have to be added the cost of plant and establishment engaged in first laying and keeping in order, but this will not raise it more than Rs. 1-8 per 1,000. Notwithstanding the saving shown in this peculiar case, and it may apply to a wet soil, I doubt the general application of this plan being practicable on an extended scale.

The plan I have adopted for working this wagon work is combined daily labor and task-work. The natives, from want of understanding mechanical arrangements, will not take this by contract, so daily labor has to be employed, and they are paid 4 annas each, on condition that, with the present lift of 22 feet, 17 men, including one bhistí at 4 annas, four men at 3½ annas, and two boys at 3 annas, take out 600 wagons of 4½ cubic feet = 2,700 cubic feet, giving a rate of Rs. 2 per 1,000; this is a full rate, and the men can make their 5 annas each by raising more.

	Rs.	A.	P.
* Plant, ...	1	4	10
General charges, ...	0	7	8
Repairs, ...	0	3	11
Labor, ...	2	12	8
Total per 1,000 cubic feet, ...	4	13	1

Statement No. 1 without bonus, gives rate per 1,000 cubic feet, Rs. 4-13-9.—R. H.

† This is the cost of actual coolie labor without Mistri, Munshi, &c., or daily repairs; plant is not included.—R. H.

Since there are not always the same men in one gang, it is impossible to pay them by measurement; but unless the work can be checked by measurement of actual excavation, there can be no certainty as to quantity done; for the wagons may not be properly filled, or the counter make mistakes, or connive with the men; so a mate of the khalási class, who can write, and who knows he will be correctly paid according to measurement, which the generality of coolies cannot believe, or do not understand, is paid 2 annas per 100 cubic feet of excavation by measurement, so it is his interest to make the men do their task; it is also theirs, for they are paid extra for the quantity in excess of 2,700 feet; and if he gets 3,000 cubic feet per day, he makes his 6 annas, or for 26 days = Rs. 9-12; and as a khalási, he would only receive Rs. 6 per month. If he is capable of looking after two lifts, he may; he then makes twice that, or Rs. 19-8, and he deserves it; for he keeps the men's time, and counts their wagons, and sees that everything is kept going.

This raises the rate to Rs. 2-2, to which has to be added the carriage by 25-cubic-feet wagons to tip head, 650 feet, which, with two lifts, will increase it by six annas, or Rs. 2-8 per 1,000.

From the experience of the two lifts, at Ráipur and Khirri, I conclude that each man should do seven miles of 5,000 feet = 35,000 feet up and down a slope of 3 to 1, for 4 annas. For getting and filling 450 cubic feet of sand, 4 annas. That for 4 annas, strong heavy men can be procured, which are absolutely necessary for raising by this mode. They are making more at Ráipur; but I had promised them for 600 wagons 4 annas each.

The man at the turn-table has easy work, but must be a strong man, to be constantly starting the wagon from a state of rest, and take it round curve, so he should get 4 annas, and he requires a man to assist him, who only turns, and he should get 3½ annas, the usual rate. A strong boy is sufficient for running on the level fulls and empties 50 feet lead; for 100 feet, two boys should be put on; for hooking on, one boy; for turning rope at wheel, a man on 3½ annas; for tipping (with the tip head kept properly by platelayer), two men should do 600 wagons, and receive 4 annas each.

Thus with a slope of 3 to 1,160 feet long,* requiring 600 lifts per day $\frac{2 \times 160 \times 600}{35{,}000 \text{ feet lineal}} = \frac{192{,}000}{35{,}000} = 5\frac{1}{2}$ sets of three men, but this half set

* This refers to the 50-feet lift at Khirri.—R. H.

might be added to their task, since it is only $\frac{1}{3}$ of $\frac{1}{3} = \frac{1}{10}$ more to do for the 15 men.

The excavation should be taken out strictly according to the centre lines shown, giving 10 feet on each side of road. The turn-table being moved every 50 feet forward. This being merely a report on the system, further details of minor points are not given.

Experiment No. 4. Mr. Derry's System.—Excavation with the aid of steam-power has been tried on two different systems, the chief distinctive features in which are the inclines or slopes up which the wagons are raised; one being on *long* inclines, and the other *short*.

The *long* incline system tried here has been described by Lieut. Miller, in whose immediate charge it was, (*vide* Experiment No. 5.) I will therefore confine myself to a description of the *short*, after stating the advantages claimed for the short over the long.

It being required to excavate a channel through a plain, the least power will be expended when the excavated material is deposited opposite the point where excavated, that is, on a line at right angles to the centre line of the channel, and the more numerous these lines, the less the power required. Any deviation from the right angled line must increase the distance the material has to be carried, and necessitate more power. With human labor with a basket, the most economical distance between these right angled lines is twice the distance a man can cast the material from the basket on his head, since it limits the distance he has to travel to the minimum, and this is what is universally done by coolie labor, unless the path from some local cause becomes too steep for his particular muscular development; but a machine winding a rope, can as easily raise a given load up vertically in a given time, as up an incline, and the nearer the vertical, the less the friction on rolling-stock in degree and continuance, requiring less power to raise, and deriving a larger portion of the descending weight of the empties, and the greater weight borne by the rope necessitating smaller but more frequent trains, which has the great advantage of the material being more easily disposed of, keeping a few men constantly employed, instead of a larger number intermittently. Further, the less weight of rope to be raised each time, also the slower speed of winding and fewer number of revolutions of winding machine, must give less wear to the machine; also the wear and tear to rolling-stock will be proportionately greater, as the

incline is longer, and therefore less steep, due to both the greater distance to travel and greater weight on axles; and the wear on the rails is greater on the long incline, on account of the greater weight of the load resting on the rails.

The incline should not be steeper than 2 to 1 on account of the difficulty of ballasting, and requiring a stronger rope, and hence larger diameter grooved pulleys; nor should it be longer than $2\frac{1}{2}$ to 1, with a section of canal such as the Sirhind.

The advantage derived from the descending wagons on a steep slope, will be best seen by comparison with a long slope, assuming the steep slope as 2 to 1, and long as 20 to 1.

The weight of an empty wagon is 800 lbs. The power required to overcome friction on a level road is 15 lbs.; so on a 2 to 1 slope, the weight being half, the friction will be half, which gives on a 2 to 1 slope a pulling force downwards of $\frac{800}{2} - \frac{15}{2} = 400 - 7\frac{1}{2} = 392{\cdot}5$ lbs.;*

* *Note by Mr. J. C. Hammer, Exec. Engineer.*

This is not quite correct. The downward pull in the direction of the slope is the load multiplied by the sine of the angle of inclination, which, for a 2 : 1 slope is about 26° 34′; the pull due to the weight of the wagon, neglecting friction, is therefore (800 × sine 26° 34′) = 357 lbs. Again, the friction is proportional to the load on the axles, and the pressure on the rails, and expressed by 15 cosine 26° 34′ = 13·41 lbs. The real down pull on this slope would be therefore 357 − 13·41 = 343 59, and not 392·5 as Mr. Derry made it.

Sine 26° 34′ .. = 0·447
Cosine 26° 34′ .. = 0·894

In the case of the long incline of $\frac{1}{20}$, the down pull due to the load, making allowance for friction, (assuming that the co-efficient of $\frac{1}{20}$ given for the latter be correct, would be 800 sine 2° 52′ − 15 cosine 2° 52′ = 40 − 14·98 = 25·02 lbs., being nearly the same as Mr. Derry's (26·75 lbs.), owing in this case to the small difference between the tangent and the sine of so acute an angle as 2° 52′.

(*Note.*—Angle of inclination of $\frac{1}{20}$, slope = 2° 52′).

I cannot quite agree with the conclusion drawn by Mr. Derry after this, *i. e.*, that the difference between the two pulls is a saving in useful effect. It strikes me he overlooked the fact, that what holds good with the empty wagons, does also hold good with the full ones; and if the *down* pull be greater in the one case, it will also be correspondingly greater in the other—in fact, that cause and effect must exactly balance each other in either case. The question of choice between steep and gentle inclines can, as far as it is argued here, and apart from consideration of length of lead, &c., only be determined by the power available or practicable to be expended in a *certain* time, *i. e.*, the speed with which the wagons can be conveniently raised, and in so far, Mr. Derry is of course right in his conclusions.

With regard to the power which Mr. Derry calculates to be expended in overcoming the excessive friction on the axles of the *full* wagons, if drawn up a long incline of $\frac{1}{20}$, and his comparison of this power with that required to overcome the friction of wagons drawn up a steep incline of $\frac{1}{2}$. I would point out that he has not, as far as I can make out, taken account in this comparison of the friction on the spindle of the drum of wheel, taking the downward pull of both empty and full wagons. This friction is directly proportional to the *joint* pull, and is the less, the greater the friction is on the axles of the wagons; this is best shown by considering the two most extreme cases as follows:—

Disadvantage of greater friction to be overcome on long inclines.

Taking this friction for an incline of $\frac{1}{\infty}$ *i. e.*, a perfectly vertical lift, there would be no fric-

and on a 20 to 1 slope $\frac{800}{20} - \frac{19 \times 15}{22} = 40 - 14{\cdot}25 = 26{\cdot}75$ lbs.; so for each wagon raised on a 2 to 1 slope, there is $392{\cdot}50 - 26{\cdot}75 = 366{\cdot}75$ lbs. less power required than on a 20 to 1 slope, due to the descending empty; and with the increased friction of the loaded ascending on a 20 to 1 slope, we shall have the saving effected by using steep slopes. The force required to overcome the friction of a loaded wagon on the level is 40 lbs.; so on a 2 to 1 slope, it will be $\frac{40}{2} = 20$ lbs.; on a 20 to 1 slope, it will be $\frac{19}{20}$ 40 ($= 38$ lbs.), multiplied by the difference of length of slopes (which is 9); so the power required to be expended to overcome friction of one loaded wagon up a 20 to 1 slope is $9 \times 38 = 342$ lbs., against 20 lbs. on the 2 to 1; there is thus a total saving of $371{\cdot}75 + (342 - 20) = 693{\cdot}75$ for each wagon raised; and since 2,000 wagons is the least number that should be raised in one day, there would be 1,387,500 lbs. power saved; and taking each loaded wagon as 2,800 lbs., 495 more wagons could be raised by an equally powerful engine on a 2 to 1 slope, than on a 20 to 1. The greater weight of rope to be raised on the long incline has not been considered, allowing that to be equal to the extra friction of more angle pulleys necessary in the short incline system.

Having shown the economy of power to raise, due to the use of short inclines, the difference in wear and tear of rolling-stock on the short and on the long incline should be compared.

The wear and tear to rolling-stock is directly proportional to the length of road and weight to be carried. The difference of length of inclines being 9, and the weight of a wagon on a 20 to 1 slope being 1·9 times greater than that on a 2 to 1 slope, the wear and tear will be $9 \times 1{\cdot}9 = 17{\cdot}1$ greater, plus the increased shaking due to greater velocity on a not perfectly laid line. The wear and tear of rails will be in proportion to the weight run over them; and since the weight on 1 in 20 is 1·9 times greater than on 1 in 2, and the incline is 9 times longer, we have $1{\cdot}9 \times 9 = 17{\cdot}1$ greater wear on rails on long, than on short, incline.

tion on the axles of the wagons, and the whole friction due to the ascending and descending loads would be on the pivots of the drum.

W = weight of full wagon on long incline.
α = angle of inclination of ditto.
w = weight of full wagons on short incline.
B = angle of inclination of ditto.
Y = co-efficient of traction.
f = co-efficient of friction on pivot of drum.

On the other hand, taking an incline $\frac{1}{c}$ as a purely horizontal draught, all the friction due to the load would be on the axles, and none, excepting that due to the tractive force (alone), would bear on the pivots of the drum. From this then follows that only the slight difference of friction due to the force required to overcome traction, that is, f (2WY sine α – 2wY sine B), can be taken into consideration in estimating the useful effect in raising loads up inclines of different declivity.

This completes the comparison of economy of power and wear and tear of rolling-stock in *lifting* the material. The "economy of power" and wear and tear of rolling-stock in conveying the excavated material from face to tip (omitting the inclines which have been compared), will be directly proportional to the distance travelled.

This will depend on the length of channel excavated from one long incline; if the same length of channel as that done by short incline, viz., 200 feet, then the cost of constructing an incline nine times as long as on the short, will be incurred to effect the same end; and if a length of channel is taken out proportional to the increased length of incline, then the excavated material will have to travel nine times as far, and the wear and tear will be nine times as great.

It would not be safe to run wagons faster than six miles an hour; and since (by using a more powerful engine), this speed can with equal safety be attained on the steep inclines with two wagons, a train of 18 wagons would have to be raised on the long to compete with it, but more than 10 is not practicable. Therefore the short incline system is capable of having raised upon it nine times as many wagons.

Having shown that the principle of short inclines is theoretically capable of effecting more work with same expenditure of power, and that more power can be applied, I will now describe the system on which short inclines have been worked here, and then the modified plan which I propose to render it most effective, after which a further comparison of the long and short inclines might be made as to "prime cost of starting," simplicity of working, and facility of shifting for erection elsewhere, and also cost of plant to effect the same on both systems.

It is supposed that it will be economical to use steam-power for the deep excavation only from 30 to 40 feet deep, and that the upper 10 feet is taken out by coolie and basket, and thrown to form a spoil 15 feet high, being the full height that the spoil need be; thus a narrow platform is formed constituting the "bank head," on which the engine is placed, and the wagons raised to.

As previously shown by reference to coolie and basket work, that the more numerous the lifting inclines are, the less the distance the material has to be carried; the distance apart of these inclined places must be fixed by considering the cost of preparing one incline against the quantity of material brought over it, and 200 feet of channel was assumed as the cor-

rect quantity. Then the number of these inclines to be worked by one engine is limited by the length of the rope that can be conveniently used; 700 feet on that required for four inclines on either side of the stationary engine was decided as the limit, and having a 12 H. P. engine to work with, fixed the quantity of work to be done, (*Plate* XXV.)

With the view of keeping the engine constantly at work, two winding drums are necessary, so that while one is hauling up and lowering wagons on four inclines, the other four are arranging their fulls and empties. To effect this, a machine was designed, consisting of two drums, round each of which two ropes are wound; the four ends of these ropes from one drum being each at an incline, one end of each rope having empties attached to it, and the other end fulls; the empties in descending keeping the rope that is wound from the inclines on which wagons are being raised tight, and thus causing the rope from its friction on the drum to bite sufficiently, to be able to raise the full wagons.

The rope as it is being wound on to the drum, of course approaches that side of the drum next the on-winding rope by the thickness of the rope, so the lift is limited by the diameter and width of drum used; hence this form of winding drum is only applicable to limited lifts, such as the excavation of a canal channel 50 feet deep; but with Fowler's dip pulleys any depth.

The advantages claimed for this form of drum are, that it is simple to construct, the power is uniform, which it is not when the rope winds on to itself, thus increasing the diameter of the drum; besides, the rope is less injured, and four drums would be required where one now answers—in fact, if this "tail end" system were not used on a traversing drum, this system of four inclines, worked simultaneously, would not be practicable (excepting with Fowler's dip pulleys); one rope on the drum is wound on the upper, and the other on the lower, and thus there is no tendency to pull the machine out of position.

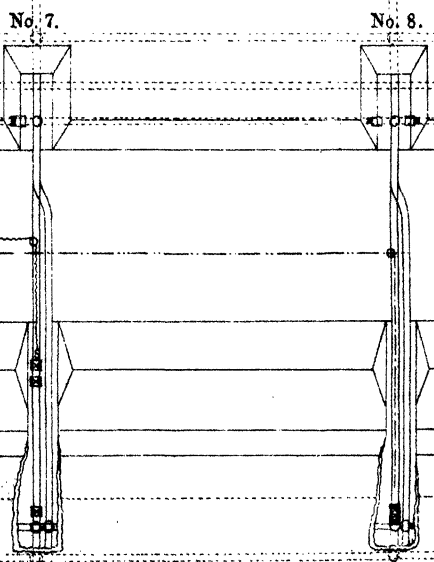
The drum has a spiral groove cut round it of $\frac{3}{4}$-inch pitch, to keep the ropes separate, and to ensure their uniform advance. The length of the ropes must be such that the empty wagons have not reached the bottom of inclines before the fulls arrive on the level at bank head, or the slack would not be pulled away, and the rope would not bite; and it has been found necessary to have a man on either side of the drum to keep the rope leaving the drum tight, in case the rope ceased being pulled away by the empties from any accident, and the men are necessary to ensure

the ropes being in their respective grooves before starting to wind, and they act as look out men to see the empty wagons are ready to start, and give notice to the driver to stop the engine if signalled to do so from any of the inclines; but they have seldom occasion to do so; but their being stationed there is a safe-guard.

The diameter of the drum should be the smallest size, that the wire rope used will not be injured in bending round it, and the practical rule in England is, that the diameter of the drum shall be 1,000 times the diameter of one wire of which the rope is made; thus, if the wires are $\frac{1}{16}$-inch diameter, the drum must be $\frac{1000}{16} = 62$ inches, or about 5 feet diameter, and all pulleys round which the rope is led should not be less, otherwise the rope will be soon injured. This fact will show the advantage in having numerous light loads to lift, instead of a few heavy ones; for wheels of a larger diameter than 5 feet would be heavy, expensive, and inconvenient to fix. For this reason, I propose to reduce the capacity of the wagons to 20 feet, instead of 25-cubic-feet as at present, this will, besides, give other advantages in making the wagons more handy, and save wear and tear by reducing the strain in the body and frame, and it would appear from the heavy repairs to the present wagons, that such reduction is needed, or that the dimensions of timbers should be increased: of course this lightening the load will not decrease the daily out-turn, for more wagons can be raised. The other remedy to decrease the size of rope is to lessen the slope, for less than two wagons cannot be used (*see Plate* XXVI.), where the wagons are shown coupled by a rope of such a length, as to allow the leading wagon to stand on the slope, thus throwing a strain on the rope ready to pull it away as soon as the engine starts. This arrangement has a further advantage in that, since the leading wagon reaches the bottom in advance of the other, there is time to uncouple it, and have it away before the other arrives. In raising, of course the wagons are close coupled. The objection to lengthening the slope is, that it will involve a greater expenditure in forming the incline, and on completion, in making up the section of canal, or it will advance too far into the excavation.

The drawings accompanying show the principal parts of the plant used in the experiment at Khirri; a written description of them is therefore unnecessary, so I will simply describe the plant that I consider necessary to render this system most efficient. Want of experience or available

HWORK



ends of ropes raising wagons leave the drum on opposite

recorded information on these points has necessitated every part of the present lift being designed here, and it could hardly be expected that it should have been perfected at once, which is my apology for it not being as successful as anticipated; but I consider the present results justify a further trial with remodelled plant as about to be described; and after Government adopting such a liberal policy in expending so much as there has been to gain this experience, it will be all thrown away if not prosecuted to completion. I cannot learn that there is an ysimilar European practice; for the conditions of excavation for railways are quite different to that for a canal; the railway cuttings being either a skimming of the ground, and where heavy, a valley must always exist that requires a heavy embankment, so that a double advantage is gained; but in canals where in "soil," the excavated material must always be thrown to spoils.

The engine should be a 16 H. P. portable, on the general design of Messrs. Robey and Co., fitted with the spiral grooved traversing drums of four of Fowler's dip pulleys, the great points in which are,—the drums are attached to the engine, being between the hind wheels, doing away with all the trouble and care required in fixing the winding machine true to the engine, and that in case of settlement, the connections are not strained—in fact, no skilled labor would be required to put this engine in position to commence work, and from the fact of the two ropes winding on different sides, there is no tendency to pull the engine in one direction only, so that no means need be taken to fasten the engine down, and work could be commenced as soon as it is wheeled into position. This is a very important point in case of extensive repairs being required to be done to it, as it could be replaced by another in the space of an hour.

This form of engine is therefore preferable for general use to the ordinary portable, being a winding engine in addition, and can transport herself from place to place; a description of this engine is given in "Engineering," 25th June, 1869. Of course, some modification would be necessary to adapt it to this purpose. The drum should be 4 feet diameter, which would not injure a rope (capable of hauling two loaded 20-cubic-feet wagons up a slope of $2\frac{1}{2}$ to 1), which would have to be 2-inch circumference, and should be made of wire, the diameter of which is $\frac{1}{1000}$ of four feet = 1·532 inches. Steel wire-rope was tried, but was found to be rapidly destroyed, due, I suppose, to its greater brittleness than iron, and therefore not able to stand jerks. The ropes on leaving the drum, should be

supported for the first 100 feet at every 20 feet by framed rollers—*see Plate* XXVII.,—diminishing in length, as they are more distant from the drum.

The object of having the rope supported only at every 20 feet here is, that it allows any slack there may be (from overhauling the wagons) to sag down, which assists the man who stands at the drum in pulling away slack as previously explained. Beyond the first 100 feet, the rope should be supported at very 10 feet. *Fig.* 5 is a drawing of the sheaves or rope carriers supported by a cast-iron spear head socket; at each ramp one rope is turned at its angles by means of a horizontal pulley; this should be not less than 4 feet diameter, and fixed as shown in *Fig.* 6. At the head of the incline, the rope is bent to an angle of 20°, and this wheel may be of a less diameter than 4 feet; for the injury to the rope doubtless has two measures, viz., the radius of the circle round which it is bent, and the force with which it is pressed against the wheel (causing the wires to grind and cut against each other), which depends on the angle that the rope forms, which, in case of being bent at right angles, gives a pressure of 1·4 times the strain on the rope, and with an angle of 20°, a pressure of ·4 times. If it were merely a question of pressure, this wheel might be one-fourth of an inch the size of the horizontal, but then the injury due to being bent to a curve of such short radius, would, I believe, be great. I am not aware of any experiments on this subject. I therefore assume that 3 feet would be about correct, and a deeper wheel in this position would be inconvenient to fix; all these wheels should be of cast-iron, with the bottom of the groove the exact size of the rope, so that it is prevented flattening out, which must cause great rubbing of the wires against each other. The wheel at bank head now referred to, is that on the line of rails up which the full wagons are raised, but there is another line parallel to it for the descent of the empties, and since they are a little more than one-third of the weight of the loaded wagons, the pulleys round which the rope must pass in letting down the empties need not be so large, and it would be difficult to arrange for the horizontal one here, being larger than 9 inches diameter; that is, therefore, the size fixed for it, and the vertical one 2 feet.

The wagons should contain 20 cubic feet only when heaped up; the present 25-cubic-feet wagon, can be conveniently altered to this, by reducing its depth from 1 foot and 3 inches to 1 foot, which facilitates loading, by having 3 inches less height to throw over. But what I consider the

most important steps towards success since I commenced designing this system is, that the wheels should be inside the frame, giving the following advantages :—1*st*, facilitating lubrication; 2*ndly*, shortening and therefore strengthening the axles; and 3*rdly*, above all, reducing the gauge, enabling much sharper curves to be used, and turn-tables being such a size as can be conveniently cast, the advantages of which I pointed out previously. There is another alteration, which I propose, that will reduce the wear and tear on axles and wheels by one-third, and therefore the friction in pulling and running; it is to increase the wheels from 15 inches diameter to 20 inches, which the present form of wagon admits of.

The wooden wagons in use here, have been found to require such very extensive repairs, that iron wagons have suggested themselves, and one has been made, but it is more expensive than wood, and somewhat heavier; but I hope to design one that will not be heavier, and its greater durability will, I believe, enable it to wear out from four to ten wooden ones. I shall, when in England, make enquiries on this subject, and I hope to be able to obtain a cheap and simple grease box, the necessity for which is lamentable in the friction and wear of axles; and I believe if a cheap form of spring could be applied, such as Adams's, the wagon would be much more durable; for the wagon bending to every inequality of the road, strains it greatly, and the roads cannot be kept in perfect order. The turn-table in pit would be a 6-throw—the two lines of rail from the slope converging into it by curves, with a mean radius of 20 feet, which it has been found that a wagon altered as above, passes round without any inconvenient friction; but, if after further trial, it is found a longer radius curve would be better, it can easily be increased.

The system of taking out the excavation with this turn-table will be the same as that described for the small wagon excavation. The turn-table on spoil will also be of cast-iron, but only a 4-throw, which will give three tip heads, two of which will only be used at one time; they being easily able to dispose of the wagons from four faces—*Plate* XXVI.,—of one incline; the two-feet-gauge roads and turn-tables are shown in the *Plate*, from which the mode of working will be evident. Since this report is merely an outline of systems tried or proposed, there will be no object in entering into greater detail of working parts; but, if required, they can be easily given. It now only remains to give a description of the mode of working, and then the cost of work actually done. On *Plates* XXV. and XXVI.,

it will be seen that each ramp or incline has two roads,* on one of which the fulls ascend only, and on the other empties only descend; the importance of this cannot be exaggerated, since it enables fulls and empties to collect below and above respectively, so that there need be the least possible loss of time in transferring the hook from one to the other.

Four ramps are worked at one time, two fulls ascending and two empties descending simultaneously on either side of the engine; the *Plate* will better explain this. On one drum ceasing to work, it is thrown out of gear, and the other drum into gear, and the other set of four ramps are worked, giving ample time for the first to be ready as soon as the drum now working ceases.

By this arrangement, the engine need only be still the time that it takes to throw one clutch out and the other in. With a 16 H. P. engine working at a pressure of 40 lbs., four wagons per three-quarter minute should be raised, or, say, 3,000 20-cubic-feet wagons per day, or 60,000 cubic feet,† working at a pressure of 40 lbs. of steam, but the engine should be constructed, so as to be capable of being pressed and worked regularly to 80 lbs. There seems to be a difference of opinion as to what these portable engines may be safely pressed and worked regularly up to, and on referring the question to Messrs. Jessop and Co., from whom some of them were bought, they gave no definite answer. I will learn this from the makers in England.

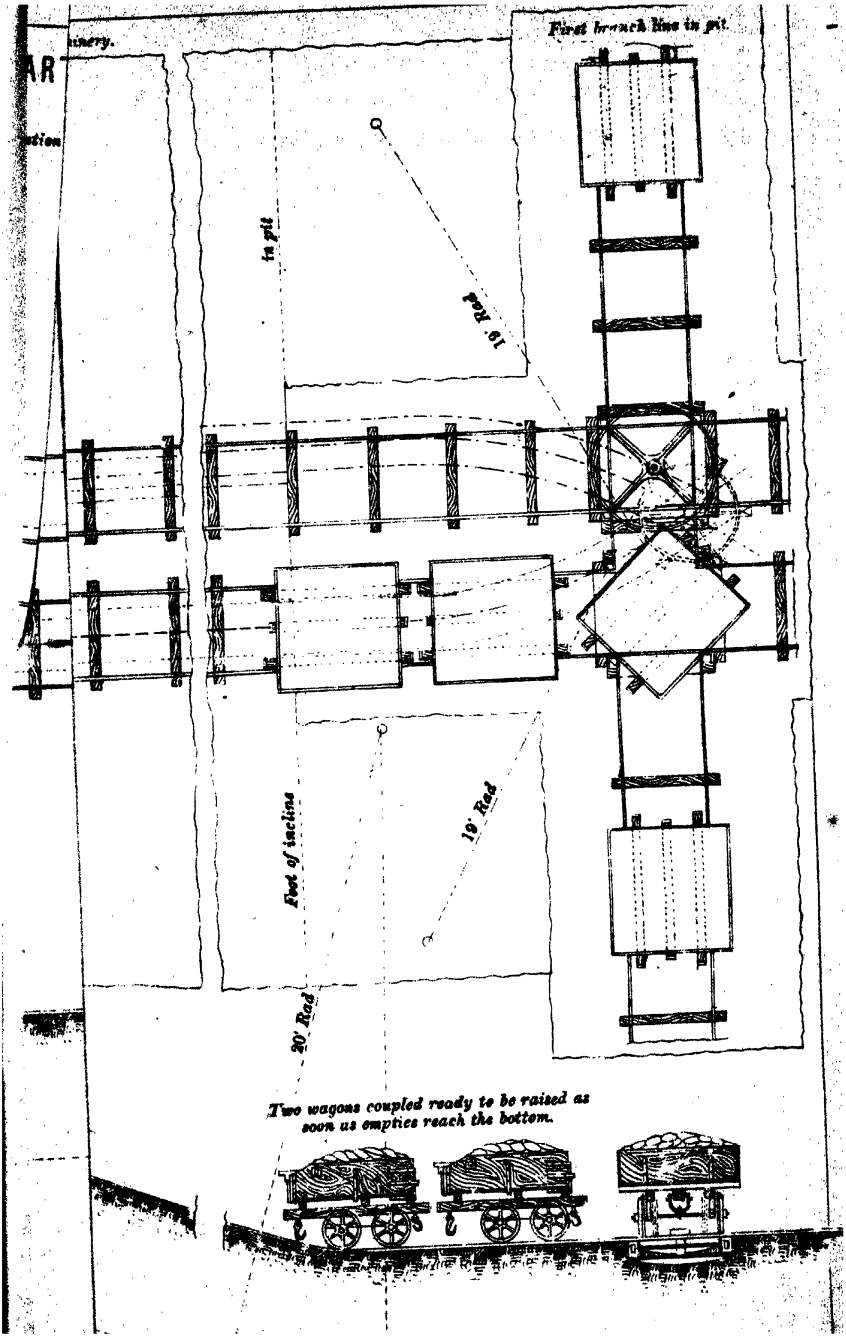
One man gets and fills 450 cubic feet of sand daily, so for getting and filling, 133 men (say 150) would be required; 50 more men for turn-tables and running wagons in pit; 48 men at tip heads; 48 men at turn-tables and running wagons on spoil; 16 men receiving and putting over wagons; 8 grease boys; 8 mates; 4 men looking after rope on drum;‡ 1 engine driver; and 1 stoker; 8 platelayers; 4 bhistís, 2 for engine; the total are number of men required.

This number of men, by increasing the number of the fillers and tip headmen, would dispose of half as many again, but the full number of men must be allowed for this ordinary rate of working to perform the different operations smartly; thus, although one could hook on the empties,

* *See* remarks in Supdg. Engineer's report, page 189.—R. H.

† *See* remarks in Supdg. Engineer's report, page 189, where he estimates 48,000 cubic feet per day as a fair average result.—R. H.

‡ Two men *might* attend to both drums.—R. H.


First branch line in pit
In pit
19' Rad
Foot of incline
19' Rad
20' Rad
Two wagons coupled ready to be raised as soon as empties reach the bottom.

it requires three to do it smartly and safely, and they could hook on four times the number in the day; again, at the turn-tables, one man is capable of working them, but two work better, but their labor is slight, and they could turn twice the number; the same for runners; so it would only be the fitters and tip-head men that would have to be increased if the raising power were increased.

	RS.	A.	P.
Then 337 men, at 4 annas (3½ is ordinary pay), ...	84	4	0
1 Driver, at 8 annas, ...	0	8	0
8 Boys, at 3 annas, ...	1	8	0
Total for labor, ..	86	4	0
Using coal fuel, at Rs. 1-6 per maund, which is certain of supply, costs Rs. 15 daily, working half the system (at a depth of 35 feet from surface and 15 feet high spoil), so twice that may be safely taken as required for working the whole system, ...	30	0	0
Grease, oil, &c., about, ...	3	12	0
Total cost for excavating 60,000 cubic feet, ..	120	0	0

or Rs. 2 per 1,000 from a depth of 35 feet; add for proportion of plant Re. 1 per 1,000 = Rs. 3. This is what the work should be done for, and what it has actually been done for will be best shown by the monthly abstracts of cost from November 1872 to April 1873, which are a history of its present working, which gives the impression that interruptions altogether opposed to rapid working were constantly occurring, and this is the strongest argument for the experiment being persisted in with the plant remodelled as before described.

The lowest rate in November was Rs. 2-1-5, using *kíkar* wood-fuel, and the greatest number of wagons raised 860 on the 30th, using coal-fuel, which is only more valuable than kíkar fuel, as 7 is to 12 by weight, the former costing Rs. 1-6 per maund, and the latter 5 annas per maund; giving a working rate of Rs. 2-12 under the unfavorable circumstances of imperfect plant and expensive fuel.

December's return shows a steady working for the whole month, giving an average rate of Rs. 3-6-6, the lowest rate being Rs. 2-14, and the greatest number of wagons raised 916, and (coal-fuel being used) which, considering the frequent interruptions by the breaking of rope and other faults in plant, which would not have occurred with properly designed plant, is favorable.

January gives an average rate of Rs. 3-4-5, the lowest being Rs. 2-12-7, and the greatest number of wagons raised 924.

February gives an average rate of Rs. 3-13-4, with fuel at Rs. 19 daily; the greatest number raised in one day being 952, and an average of 800 daily. The shaft broke on 15th, which was attributed to a flaw in the iron.

March. The shaft having been replaced, the work was re-commenced, but the valuable alteration of making a double line on inclines having suggested itself, work was stopped to make it, and work was re-commenced on 9th April, but with no improved results, due to men being short, they having gone to harvest. On the 21st the shaft again broke when I inspected it; it was due to want of strength; and on calculating it, found it to be the case—4½ inches being required instead of 3 inches; the shaft is ready, and work will be shortly re-commenced.

It must be remembered that only one-half the system was working during this time, so the number raised is half what it would be with the whole.

These results do not take into consideration the cost of preparing plant, for since it has been entirely experimental, numerous changes have been made, which have been very expensive; this has been given in previous returns, but would be of no value in arriving at what the work can be done for, which the above monthly abstracts of expenditure do.

I have shown that theoretically this system is more economical than the long incline system, and the actual working of the months quoted, shows that on some days it is very economical; and also that when it was not so, it was some fault in mechanical detail, which faults I have pointed out, and shown how they can be remedied, so the conclusion is incontrovertible, that with perfect plant, the theoretical rate of Rs. 2 per 1,000 from 35 feet excavation can be ensured.

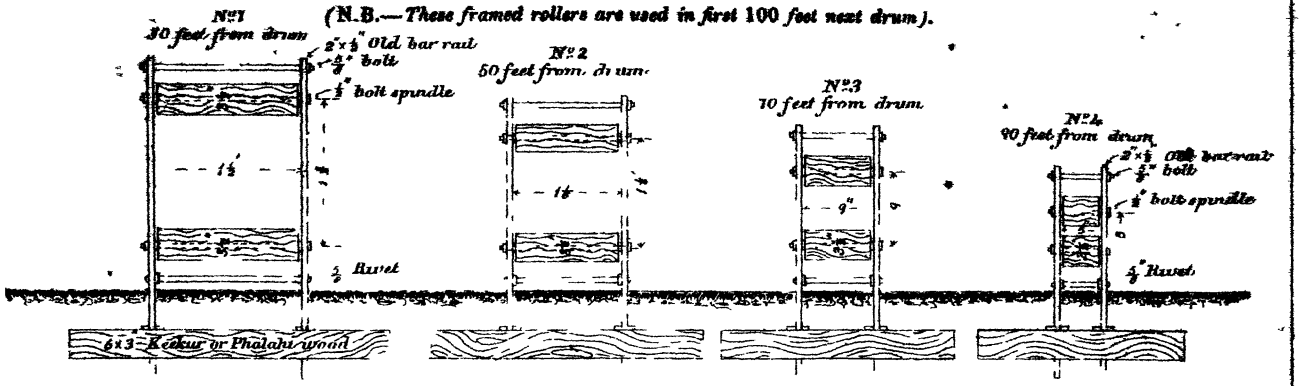
There is the one objection, that unless the plant was required elsewhere excavation by this means on an extensive scale would have to bear the whole cost of the plant, and the contingent expense of workshops for repairs; but they would be on a limited scale if the plant was imported (especially iron wagons), excepting all cast-iron work, which can well and cheaply be procured from Náhan and Roorkee; but since almost every part is better of iron than wood (and possibly also even sleepers), there would be a considerable return from its sale as old iron. I am supposing that arrangements would be made for 10 miles of 35 feet deep excavation to be taken out in three years, at the termination of which, the plant might not be required elsewhere, so must be charged to the work. To ef-

EARTHWORK EXPERIMENTS ON SIRHIND CANAL.

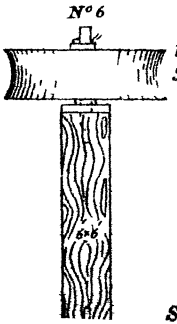
EXPERIMENT No. 4.—MR. DERBY'S SYSTEM.

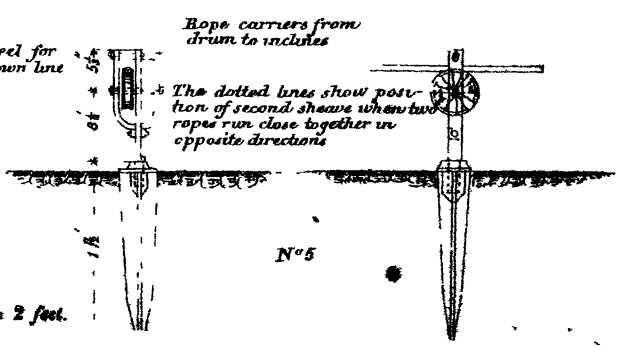
ROLLERS FOR SUPPORTING WIRE ROPE ON ENGINE LIFT No. 1.

(N.B.—These framed rollers are used in first 100 feet next drum).









Scale 1½ inch = 2 feet.

superficial feet section × 10 miles of 5,000 feet = 471,200,000.* Each engine takes on 1,600 feet of channel = $\frac{50,000}{1,600}$ feet = 31 double engine lifts (since half channel is only done at one time) doing 9,424 × 1,600 = 15,078,400, which at 60,000 (*a*) daily, will occupy 251 (*b*) days, say one (*c*) year; so allowing for four (*d*) changes in three years; each engine will do 352 (*e*) lakhs, and $\frac{4,712 \text{ lakhs (total)}}{352 \text{ one engine's duty}}$ (*f*) = 13 (*g*) engines and plant complete, to be charged against this work; and allowing Rs. 2 per 1,000 as the rate at which it has been shown the work can be done, the work would cost Rs. 9,42,400, and by coolie and basket Rs. 4-4, the rate will have actually, when the lower lifts are finished, cost here Rs. 20,02,600, leaving 10½ lakhs allowable for plant; and since each lift would require,

	Rs.
One winding engine, ...	6,000 (*h*)
5,600 yards, 14 lbs. per yard, rail, at Rs. 7 (*i*) per maund, ..	19,000
12 wagons on each incline, or 96 for whole lift, and allow one-half for repairs, extra 144, say 150 wagons, at Rs. 100 each, ..	15,000
Carried forward, ..	40,000

* This calculation is incorrect in itself; further Mr. Derry has made no allowance for the upper 10 feet in depth of excavation, which will be taken out by coolies and baskets (under all circumstances the cheapest method for light digging), to form the bank head (*vide* page 164). The area of section will then become 9,424 − 3,110 = 6,314 square feet. The contents of 10 miles 6,314 × 50,000 = 315,700,000 cubic feet; 6,314 × 1,600 = 10,102,400 cubic feet; the excavation to be done by two engines facing each other, which will finish their work at the rate of 1,20,000 cubic feet (two engines at 60,000 each) a day in 85 days (say one-third of a year). Then in three years (allowing nine shifts in that time (a pair of engine lifts would have taken out 910 lakhs cubic feet, or each engine 455 lakhs. And $\frac{3157}{455}$ = 6·94, or, say,† seven engines, which is about half the number arrived at by Mr. Derry.—R. H.

† Add one spare engine; grand total eight engines.—R. H.

(*a*). 1,20,000.
(*b*). 126.
(*c*). Half.
(*d*). Six.
(*e*). 453.
(*f*). $\frac{4712}{453}$.
(*g*). 11. Add two spare engines; grand total 13 engines.—R. H.
(*h*). Rate low; nearer Rs. 8,000.—R. H.
(*i*). Rate low; say Rs. 8-8; calculation is wrong; at Rs. 7 the amount will be Rs. 6,860.—R. H. These are evidently supposed to be *wooden* wagons. The *amount* may be left, as the iron wagons will probably be more expensive, and in the latter case, the allowance for spare wagons and repairs is evidently exorbitant.—R. H.

		RS.
Brought forward, ..		40,000
16 turn-tables of cast-iron, at Rs. 80 each, allowing for repairs Rs. 1,280, say, ...		1,500
8 angle wheels of cast-iron, at Rs. 30 each, ..	Rs. 240	
16 „ „ at Rs. 25 (*a*) each,	„ 400	
320 rollers, at Rs. 3 each, ...	„ 960	1,600
6,400 feet of wire rope (*b*) renewed three times in three years, at Re. 1 per yard, ...		6,400
Non-perishable, being iron, ...		49,500
Sleepers for 2,860 yards of road = 2,800, at 4 annas each, ...	Rs. 1,200	
Bumpers and spikes, and sundries and contingencies,	„ 3,300	4,500
Total prime cost for one lift, ...		54,000*

(*a*). I have increased the rate of 8 of these to Rs. 30.—R. H.

(*b*). Not sufficient; it is true the rope only wears at the ends, which can be renewed independently; but still I think the allowance had better be doubled—R. H.

* I think that the subjoined estimate is fairer than Mr. Derry's.

Serial numbers.		RS.
1.	1,400 lineal yards of road (being half of the 2,800 yards total estimated by Mr. Derry), which may be supposed to be formed before commencement of work. From actual experiment at Rájpur, it was found that preparing the ground and inclines cost Rs. 39 per 100 yards, ...	546
2.	2,800 lineal yards tramway is estimated at per yard—	
	RS.	
	Two yards 14-lb. rail, at Rs. 8-8 per maund, ... 2·975	
	One sleeper, at 4 annas, ... 0·25	
	Laying road, spikes, carriage, &c., ... 0·40	
	Per yard, total, ... 3·625	10,150
3.	8 sets of points and crossings, complete on bank, at Rs. 25 each, ...	200
4.	16 cast-iron turn-tables (8, 6-throw, and 8, 4-throw), at Rs. 80 each, ...	1,280
5.	1 16 H. P. engine, with drums complete, ...	8,000
	Erecting the above, temporary shed, &c., ...	150
6.	8 cast-iron angle wheels, 4 feet diameter, } 16, at Rs. 30 each, ...	480
7.	8 „ „ 3 „ „ }	
8.	8 „ „ 9 inches diameter, at Rs. 25 each, ...	200
9.	320 guide rollers, with sockets complete, at Rs. 3 each, ...	960
10.	6,400 yards wire rope, 2¼ inch; rate includes six renewals in 3 years, at Rs. 2 per yard, ...	12,800
11.	150 wooden 20-cubic-feet wagons, at Rs. 100 each, ...	15,000
12.	Small tools, picks, pharoahs, &c., ...	300
	Total, ...	50,066
	Add contingencies, at 5 per cent., ...	2,503
	Grand total, cost of one lift, ...	52,569

The above is the cost of the system erected, and ready for work on Sirhind Canal.

and for 13 lifts = 7,02,000, against 10½ lakhs to spare, without allowing anything for the value of plant at termination of work, one-eighth of the non-perishable portion of which might be safely calculated on = $\frac{49500}{8} \times 13$ = 80,400. But supposing there was no saving, the question of time would, in ground that labor would not take to, necessitate its adoption. It has been shown that for one engine lift 350 men are required, then for 13 lifts = 4,550 men—a number which at such high rates as 4 annas, would be safely calculated on, and to do the same quantity of work in the same period, allowing each man to do 50 cubic feet daily, which including women and children, is a fair average $\frac{\frac{471,200,000 \text{ c. ft.}}{1050 \text{ days}}}{50 \text{ c. ft.}} = 8,974$, or twice the number, or twice the time, and if working in wet soil, it is almost imposible to get men to take the work, from having to carry it on their heads, which wets and gives them fever.

To make a further experiment with the modified plant would cost—

	RS.	RS.
To alter wagons to 2 feet gauge, and reduce to 20 cubic feet,	1,000	
One engine, ...	6,000	
16 turn-tables, at Rs. 80, say, ...	1,500	
Cast-iron angle wheels and new rollers, ...	1,600	
Wire rope, ...	2,100	12,200
Rails we have, also sleepers, but for sundries, say, ...		2,800
Total to complete experiment, ...		15,000

Note.—I would further offer the subjoined revised estimate on excavation of 10 miles of canal 35 feet deep, based on my remarks in foot notes on pages 170 and 174, and on the above statement.

	RS.
Cost of top lift by coolies and baskets—	
155,500,000 cubic feet, at, *say*, Rs. 3 per 1,000 cubic feet, ... =	4,66,500
Duty of one engine in one position = $\frac{10,102,400}{2}$ cubic feet = 5,051,200.	
Then $\frac{5,051,200 \text{ cubic feet}}{48,000 \text{ (page 170)}}$ = 105 days.	
And in three years of 280 days, there would be $\frac{840}{105}$ = 8 shifts.	
Also ,, ,, one engine would have taken out 5,051,200, by 8 = 40,409,600 cubic feet.	
Then $\frac{3157}{404}$ lakhs = 7·8, say eight engines and lifts complete, to which add one spare *engine* to replace those under repair,	
Total eight lifts complete, at Rs. 52,569 each, ... =	4,20,552
One spare engine, at Rs. 8,000, ... =	8,000
Cost of plant and erection, ... =	4,28,552
Carried forward, ...	4,66,500

The foregoing arguments are to prove that short inclines are preferable to long ones, and with the hope that the short inclines may have a further trial; but unless it can also be shown that it is the cheapest of any mode of excavation, the argument may result in nothing. Thus, excavation with the aid of a locomotive, has its advocates as the cheapest and quickest. As to the economy, I am unable to understand how it can be; for to raise a load a certain height can only be effected by a definite expenditure of power, and this the locomotive must have in common with a portable; but to enable it to work, long inclines must be used, up which it also has to raise its own weight, gaining no advantage by its, and the empties descent, and the distance the wagons and engine must travel must give proportional wear and tear, and since this is (supposing two miles of canal, which is considered the limit) 5,000 to 250, the wear and tear must be 20 times as great as on a short incline system. The expedition due to being able to use more powerful engines is its advantage, which can only be effected in portable engine lifts by increasing their number after the greatest safe speed of raising (I should say six miles an hour) has been attained. The speed at which the wagons are raised to effect 60,000 cubic feet is under two miles an hour; so, if increased to four, and other arrangements made in excavating and tipping, twice 60,000 or 1,20,000 could be raised, and this would be arranged for were it sanctioned.

	Rs.	Rs.
Brought forward, ...		4,66,590
Deduct recoverable—		
One-eighth items (foot note, page 173) 2 to 11 by 8 lifts =		
$\frac{43,120 \times 8}{8} + \frac{8000}{8}$ ... ... =	44,120	
Total chargeable to works, =	3,84,432	

This gives a rate per 1,000 cubic feet of 315,700,000 cubic feet of Rs. $\frac{384432}{315700}$ =

Rs. 1-3-4, say Rs. 1-4 per 1,000 cubic feet.

Rejecting from Mr. Derry's detail of labor on page 171, extra fillers, &c., required for the 60,000 instead of 48,000 cubic feet of work per diem, rate for labor &c., will be Rs. 2-4 per 1,000 cubic feet. This gives a total average rate for work performed by engine lift from 10 to 35 feet deep of Rs. 3-8 per 1,000 cubic feet, which is probably slightly in excess of what the work can be done at.

315,700,000 cubic feet, at Rs. 3-8 per 1,000, ... =		11,04,950
Total of cost of labor and plant on 10 miles, ... =		15,71,450
Cost of the ab 471,200,000 cubic feet, at Rs. 4-4 per 1,000 (page 173), ... =		20,02,600
In favor of the engine lifts, ...		4,31,150

R. H.

	Fuel.			Oil and tallow.			General stores.			Daily labor.			Monthly labor.			Total labor.			Total stores.			Grand Total.			No. of hours at work with wagons.	No. of wagons.	Contents.	Price per 1000 cubic feet.			Remarks.
	RS.	A.	P.	RS.	A	P.	RS.	A.	P.	RS.	A	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.				RS.	A.	P.	
	..	..	..	..	..	..	..	..	..	19	9	9	2	14	11	22	8	8	..	..	..	22	8	8	..	..	3,689	..	..	..	
	5	9	9	1	15	5	0	7	3	20	14	3	2	14	11	23	13	2	8	0	5	31	13	7	10	592	13,912	2	4	7	Basket work.
	..	..	..	..	..	..	..	..	..	5	6	6	..	..	..	5	6	6	..	..	..	5	6	6	..	..	..	..	..	..	
	5	9	9	1	15	5	0	7	3	26	5	0	2	14	11	29	3	11	8	0	5	37	4	4	10	736	17,296	2	1	5	Platelaying.
	5	9	9	1	15	5	0	7	3	27	2	0	2	14	11	30	0	11	8	0	5	38	1	4	10	562	13,207	2	14	1	Excavation with baskets as well. Work not measured.
	5	9	9	1	15	5	0	7	3	27	11	9	2	14	11	30	10	8	8	0	5	38	11	1	10	568	13,348	2	14	4	Old rope broken; commenced putting in new one; guard rails put in all curves above and below, about 300 feet rails bent for this purpose; in most cases flanges on one side also cut. All wagons distributed according to gauge of wheels.
	2	13	0	0	9	6	0	2	3	27	13	0	2	14	11	30	11	11	3	8	9	34	4	8	3	180	4,230*	..	..	..	
	..	..	..	..	..	..	..	..	..	27	11	0	2	14	11	30	9	11	..	..	..	30	9	11	..	..	2,960	..	..	..	Nos. 2 and 3 ramps; gauge of rails altered from 3 feet 2 inches, to 3 feet 1½ inches for small gauge wheels.
	..	..	..	..	..	..	..	..	..	27	5	0	2	14	11	30	3	11	..	..	..	30	3	11	..	..	3,690	..	..	..	Roads below at Nos. 1 and 4 lowered; former 2 feet, latter 4 feet; in each case about 40 feet length of both roads below taken up together, with bent rails at bottom of slope elongated, &c. All roads repaired with red earth under and above sleepers.
	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
	..	..	..	..	..	..	..	..	..	22	15	6	2	14	11	25	14	5	..	..	..	25	14	5	..	..	3,550	..	..	..	
	..	..	..	..	..	..	..	..	..	22	6	6	2	14	11	25	5	5	..	..	..	25	5	5	..	..	3,760	..	..	..	† 1,900 of this excavated with baskets.
	..	..	..	..	..	..	..	..	..	23	1	3	2	14	11	26	0	2	..	..	..	26	0	2	..	..	4,328	..	..	..	Commenced with wagons at 2½ P. M.; new rope somewhat injured by bad driving of engine; 12 hooks broken
	..	..	..	..	..	..	..	..	..	23	12	4	2	14	11	26	11	3	..	..	..	26	11	3	..	..	6,615	..	..	..	
	..	..	..	..	..	..	..	..	..	25	9	3	2	14	11	28	8	2	..	..	..	28	8	2	..	..	4,050	..	..	..	
	2	10	11	0	7	10	0	1	10	26	14	0	2	14	11	29	12	11	3	4	7	33	1	6	2½	140	5,190†	..	..	..	
	..	..	..	..	..	..	Sunday.			0	7	0	..	..	..	0	7	0	..	..	..	0	7	0	..	..	..	..	..	..	Commenced with engine: no water could be kept in boiler, fire taken out, all new joints blowing, together with a bolt and the lead plug in fire-box.
	0	4	9	0	1	8	0	0	6	28	11	0	2	14	11	31	9	11	0	6	11	32	0	10	¼	..	6,160				All water in boiler allowed to escape through aperture of safety valve. Set to basket work.
	3	3	6	0	9	6	0	2	3	29	9	6	2	14	11	32	8	5	3	15	3	36	7	8	3	192	*a* 7,670				‡ New rope broken.
	2	2	4	0	6	2	0	1	4	29	9	6	2	14	11	32	8	5	2	9	10	35	2	3	2	104	*b* 6,393‡				Ditto.
	5	5	10	0	15	8	0	3	6	30	4	0	2	14	11	33	2	11	6	9	0	39	11	11	5	320	*c* 9,980				
	10	11	4	1	15	5	0	7	3	30	13	0	2	14	11	33	11	11	13	2	0	46	13	11	10	514	12,079	3	14	1	21 cubic feet to a wagon after this date. [broken.
	10	11	4	1	15	5	0	7	3	30	12	9	2	14	11	33	11	8	13	2	0	46	13	8	9	714	14,994	3	1	11	Obliged to stop at 4½ P. M. Fly wheel loose; 3 hooks
	..	..	..	..	..	..	..	..	..	0	15	9	Sunday.			..	..	..	..	..	..	0	15	9	..	..	..	..	..	..	Taking off pinion wheel; putting on new one, clearing and filling engine.
	10	11	4	1	15	5	0	7	3	30	9	6	2	14	11	33	8	5	13	2	0	46	10	5	10	680	14,280	3	4	3	18 hooks broken.
	10	11	4	1	15	5	0	7	3	30	9	0	2	14	11	33	7	11	13	2	0	46	9	11	10	520	10,920	4	4	3	New rope broken. Work retarded; two ramps only working for about 2½ hours.
	10	11	4	1	15	5	0	7	3	30	5	6	2	14	11	33	4	5	13	2	0	46	6	5	10	344	7,224	..	..	..	New ropes changed for old ones.
	10	11	4	1	15	5	0	7	3	30	15	6	2	14	11	33	14	5	13	2	0	47	0	5	10	640	13,440	2	12	0	20 c. ft. to a wagon after this date: one hook broken.
	10	11	4	1	15	5	0	7	3	32	3	0	2	14	11	35	1	11	13	2	0	48	3	11	10	768	15,360	3	2	3	One hook broken.
	10	11	4	2	0	1	0	8	1	31	6	0	2	15	1	34	5	1	13	3	6	47	8	7	10	860	17,200	2	12	2	Ditto, M S.
																															Note—Consumption of coal as fuel, ... 7 34 average per day. Do. do. of wood 13 10 "
als for																															Rate of coal per maund, ... Rs. 1 "6 0
onth,	125	10	0	26	12	0	6	3	6	721	12	1	76	4	0	798	0	1	158	9	6	956	9	7	135	..	2,35,516	4	1	4	Average price of earthwork for this month per 1,000 cubic feet, ... " 4 1 4

Engine Lift No. 1.—Abstract of Labor, &c., for December, 1872.

Fuel.			Country oil and tallow.			General stores.			Daily labor.			Monthly labor.			Total labor.			Total stores.			Grand Total.			No. of hours at work.	No. of wagons	Contents.	Price per 1000 cubic feet.			Remarks.
RS.	A.	P.	RS.	A.	P.	RS.	A	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.				RS.	A.	P.	
..	..	..	..	..	..	..	..	..	4	9	9	2	9	9	7	3	6	..	..	..	7	3	6	..	..	..	..	..	..	Platelaying.
15	9	2	1	3	0	0	1	11	31	13	0	2	9	9	34	6	9	16	14	1	51	4	10	10	856	17,120	2	15	11	Wagons running off line at No. 1 opposite crossing on slope.
..	..	..	..	..	..	..	..	..	1	4	0	2	9	9	3	13	9	..	..	..	3	13	9	..	..	..	..	..	..	Holiday for Ede. Repairing wagons and platelaying.
15	9	2	1	3	0	0	1	11	30	15	6	2	9	9	33	9	3	16	14	1	50	7	4	10	832	16,640	3	0	6	
15	9	2	1	3	0	0	1	11	33	5	0	2	9	9	35	14	9	16	14	1	52	12	10	10	860	12,700	3	1	1	
15	9	2	1	3	0	0	1	11	34	11	0	2	9	9	37	4	9	16	14	1	54	2	10	10	916	18,320	2	15	3	
15	9	2	1	3	0	0	1	11	30	14	6	2	9	9	33	8	3	16	14	1	50	6	4	10	874	17,480	2	14	1	
..	..	..	..	..	..	..	..	..	0	14	3	2	9	9	3	8	0	..	..	..	3	8	0	..	..	..	..	..	..	Could not commence for ¼ an hour. Fitters at work
11	10	11	1	3	0	0	1	11	26	5	0	2	9	9	28	14	9	12	15	6	41	14	3	7½	508	10,160	4	1	10	with engines, spur and pinion; only ¼ in gear, stopped for two hours to re-fit.
15	9	2	1	3	0	0	1	11	31	9	6	2	9	9	34	3	3	16	14	1	51	1	4	10	772	15,440	3	5	0	Wire rope broken at No. 1 repaired, working with
15	9	2	1	3	0	0	1	11	30	10	6	2	9	9	33	4	3	16	14	1	50	2	4	10	852	17,040	2	15	1	two ramps only
15	9	2	1	3	0	0	1	11	26	5	0	2	9	9	28	14	9	16	14	1	45	12	10	10	720	14,400	3	2	10	
15	9	2	1	3	0	0	1	11	31	2	0	2	9	9	33	11	9	16	14	1	50	9	10	10	868	17,360	2	14	7	Wire rope again broken at No. 1, working for 4¼
15	9	2	1	3	0	0	1	11	24	13	0	2	9	9	27	6	9	16	14	1	44	4	10	10	600	12,000	3	11	0	hours with two ramps; new pieces 180 feet long spliced on No. 1 rope.
..	..	..	..	..	..	..	..	..	2	6	6	2	9	9	5	0	3	..	..	..	5	0	3	..	..	..	..	..	..	
15	9	2	1	3	0	0	1	11	30	2	0	2	9	9	32	11	9	16	14	1	49	9	10	10	824	16,480	2	15	11	Late in getting up steam, owing to one inch brick wall in fire-box.
4	10	9	1	3	0	0	1	4	7	13	0	2	9	9	10	6	9	5	15	1	16	5	10	3	188	3,760	4	5	7	Raining, coolies sent away.
15	9	2	1	3	0	0	1	11	26	10	6	2	9	9	29	4	3	16	14	1	46	2	4	10	740	14,800	3	1	10	Short of coolies; commenced with 10 men at each ramp.
5	7	0	1	3	0	0	1	11	25	12	6	2	9	9	28	6	3	6	11	11	35	2	2	4	348	6,960	5	0	9	Stopped work at 10½ A. M.; exposed surfaces of supports of engine and machine.
..	..	..	..	..	..	..	..	..	25	14	6	2	9	9	28	8	3	..	..	..	28	8	3	..	..	3,768	7	9	1	Working with baskets.
..	..	..	..	..	..	..	..	..	24	11	3	2	9	9	27	5	0	..	..	..	27	5	0	..	..	4,594	5	15	1	
..	..	..	..	..	..	..	..	..	3	12	9	2	9	9	6	6	6	..	..	..	6	6	6	..	..	..	..	..	..	
15	9	2	1	3	0	0	1	11	31	4	6	2	9	9	33	14	3	16	14	1	50	12	4	10	824	16,480	3	1	3	
15	9	2	1	3	0	0	1	11	26	12	6	2	9	9	29	6	3	16	14	1	46	4	4	10	758	15,160	3	0	10	
239	13	0	20	2	0	2	1	0	544	8	0	62	10	5	607	2	5	262	0	0	869	2	6	154¼	..	2,55,162	3	6	6	Average rate per month, Rs. 3-6-6.

Monthly Abstract of Cost of Labor on Engine Lift No. 1, for the Month of January, 1873.

Fuel.			Oil and tallow.			General stores.			Daily labor.			Monthly labor.			Total labor.			Total stores.			Grand Total.			No. of hours at work.	No. of wagons.	Contents.	Price per 1000 cubic feet.			Remarks.
RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.				RS.	A.	P.	
15	6	2	1	9	4	0	1	6	27	10	6	2	8	11	30	3	5	17	1	0	47	4	5	9½	740	14,800	3	3	1	
15	6	2	1	9	4	0	1	6	27	15	6	2	7	5	30	6	11	17	1	0	47	7	11	9½	752	15,040	3	2	6	
15	6	2	1	9	4	0	1	6	26	8	0	2	7	5	28	15	5	17	1	0	46	0	5	9½	848	16,960	2	11	4	
..	..	..	..	..	..	..	..	..	2	11	0	2	7	5	5	2	5	..	..	..	5	2	5	..	..	..	..	..	..	Platelaying ; moving turn-tables.
15	6	2	1	9	4	0	1	6	28	3	6	2	7	5	30	10	11	17	1	0	47	11	11	9½	748	14,960	3	3	0	
15	6	2	1	9	4	0	1	6	31	12	2	2	7	5	34	3	7	17	1	0	51	4	7	9½	860	17,200	2	15	8	
15	6	2	1	9	4	0	1	6	29	8	0	2	7	5	31	15	5	17	1	0	48	10	5	9½	780	15,600	3	2	3	
15	6	2	1	9	4	0	1	6	31	8	6	2	7	5	33	15	11	17	1	0	51	0	11	9½	800	16,000	3	3	0	
15	6	2	1	9	4	0	1	6	30	14	0	2	7	5	33	5	5	17	1	0	50	6	5	9½	788	15,760	3	3	2	
15	6	2	1	9	4	0	1	6	28	13	9	2	7	5	31	5	2	17	1	0	48	6	2	9½	868	17,360	2	12	7	
..	..	..	..	..	..	..	..	..	1	4	6	2	7	5	3	11	11	..	..	..	3	11	11	..	..	..	..	..	..	Ditto. ditto.
15	6	8	1	9	4	0	1	6	33	1	6	2	7	5	35	8	11	17	1	6	52	10	5	9½	920	18,400	2	13	9	
15	6	2	1	9	4	0	1	6	33	7	0	2	7	5	35	14	5	17	1	0	52	15	5	9½	924	18,480	2	13	10	
15	6	2	1	9	4	0	1	6	33	15	0	2	7	5	36	6	5	17	1	0	53	7	5	9½	920	18,400	2	14	5	
15	6	2	1	9	4	0	1	6	27	11	0	2	7	5	30	2	5	17	1	0	47	3	5	9½	728	14,560	3	3	10	
..	..	..	..	..	..	..	..	..	4	8	0	2	7	5	6	15	5	..	..	..	6	15	5	..	..	..	..	..	..	Platelaying ; wire rope broken ; a rope made up
..	..	..	..	..	..	..	..	..	4	4	0	2	7	5	6	11	5	..	..	..	6	11	5	..	..	..	..	..	..	of best pieces to be found ; rest of men employed
..	..	..	..	..	..	..	..	..	0	10	6	2	7	5	3	1	11	..	..	..	3	1	11	..	..	..	..	..	..	in making slopes, &c , for new ramps. New an-
..	..	..	..	..	..	..	..	..	4	5	0	2	7	5	6	12	5	..	..	..	6	12	5	..	..	..	..	..	..	gle wheels put in.
..	..	..	..	..	..	..	..	..	4	5	6	2	7	5	6	12	11	..	..	..	6	12	11	..	..	..	..	..	..	
..	..	..	..	..	..	..	..	..	4	12	0	2	7	5	7	3	5	..	..	..	7	3	5	..	..	..	..	..	..	
15	6	2	1	9	4	0	1	6	23	15	0	2	7	5	26	6	5	17	1	0	43	7	5	9½	588	11,760	3	11	1	
15	6	2	1	9	4	0	1	6	28	10	0	2	7	5	31	1	5	17	1	0	48	2	5	9½	768	15,360	3	2	1	
15	6	2	1	9	4	0	1	6	15	0	6	2	7	5	17	7	11	17	1	0	34	8	11	9½	440	8,800	3	14	9	
..	..	..	..	..	..	..	..	..	4	2	0	2	7	5	6	9	5	..	..	..	6	9	5	..	..	..	..	..	..	Platelaying ; moving turn-tables.
15	6	2	1	9	4	0	1	6	15	15	0	2	7	5	18	6	5	17	1	0	35	7	5	9½	482	9,640	3	10	10	
15	6	2	1	9	4	0	1	6	23	7	0	2	7	5	25	14	5	17	1	0	42	15	5	9½	604	12,080	3	8	10	
15	6	2	1	9	4	0	1	6	26	8	6	2	7	5	28	15	11	17	1	0	46	0	11	9½	812	16,240	2	13	4	
15	6	2	1	9	4	0	1	6	27	3	6	2	7	5	29	10	11	17	1	0	46	11	11	9½	764	15,280	3	0	9	
15	6	2	1	9	4	0	1	6	29	14	6	2	7	5	32	5	11	17	1	0	49	6	11	9½	800	16,000	3	1	5	
323	2	0	33	4	0	1	15	6	612	8	11	74	0	0	686	8	11	358	5	6	1,044	14	5	..	15,934	3,18,680	3	4	5	

Engine Lift No. 1.—*Abstract of Labor, &c., for the Month of February*, 1873.

Fuel.			Oil and tallow.			General stores.			Daily labor.			Monthly labor.			Total labor.			Total stores.			Grand Total.			No. of hours at work.	No. of wagons.	Contents.	Price per 1000 cubic feet.			Remarks.
RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A	P.				RS.	A.	P.	
19	0	0	1	2	9	0	1	1	32	11	6	2	9	4	35	4	10	20	3	10	55	8	8	10	860	17,200	3	3	10	
..	..	..	..	..	..	..	..	..	0	7	0	2	9	4	3	0	4	..	..	..	3	0	4	..	..	..	..	..	..	
19	0	0	1	2	9	0	1	6	32	12	0	2	9	4	35	5	4	20	4	3	55	9	7	10	788	15,760	3	8	4	
19	0	0	1	2	9	0	1	1	35	10	6	2	9	4	38	3	10	20	3	10	58	7	8	10	952	19,040	3	1	1	
19	0	0	1	2	9	0	1	1	38	6	0	2	9	4	40	15	4	20	3	10	61	3	2	10	952	19,040	3	3	5	
19	0	0	1	2	9	0	1	1	41	9	6	2	9	4	44	2	10	20	3	10	64	6	8	10	864	17,280	3	11	7	
19	0	0	1	2	9	0	1	1	40	8	6	2	9	4	43	1	10	20	3	10	63	5	8	10	780	15,600	4	0	11	
19	0	0	1	3	0	0	1	1	41	8	0	2	9	4	44	1	4	20	4	1	64	5	5	10	780	15,600	4	1	11	
..	..	..	..	..	..	..	..	..	2	3	9	2	9	4	4	13	1	..	..	..	4	13	1	..	..	..	..	..	..	
19	0	0	1	2	9	0	1	1	37	9	0	2	9	4	40	2	4	20	3	10	60	6	2	10	816	16,320	3	1	2	Two wagons broken to pieces running down
19	0	0	1	2	9	0	1	1	36	15	0	2	9	4	39	8	4	20	3	10	59	12	2	10	692	13,840	4	5	0	the slope.
19	0	0	1	2	9	0	1	1	38	7	6	2	9	4	41	0	10	20	3	10	61	4	8	10	780	15,600	3	14	4	One strand of rope broken near the drum.
19	0	0	1	2	9	0	1	1	38	9	3	2	9	4	41	2	7	20	3	10	61	6	5	10	644	12,880	4	12	2	*Do.* do. 15 feet from hook No. 3.
19	4	0	1	2	9	0	1	1	38	9	6	2	9	4	41	2	10	20	7	10	61	10	8	10	756	15,120	4	1	2	
19	4	0	1	2	9	0	1	1	38	9	6	2	9	9	41	3	3	20	7	10	61	11	1	10	724	14,480	4	4	1	
																														Shaft of machine broken; work stopped. Again started on the 24th March.
247	8	0	15	4	0	0	14	6	494	8	6	38	11	5	533	3	11	263	10	6	796	14	5	13	10,388 (800 nearly)	2,07,760	3	13	4	

Engine Lift No. 1.—Abstract of Labor, &c., for March, 1873.

e.	Fuel.			Oil and tallow.			General stores.			Daily labor.			Monthly labor.			Total labor.			Total stores.			Grand Total			Number of hours at work.	Number of wagons.	Contents	Price per 1000 cubic feet.			Remarks.
	RS.	A	P.	RS.	A.	P.				RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.				RS.	A.	P.	
h	15	3	0	0	15	5				40	14	0	2	6	0	43	4	0	16	2	5	59	6	5	10	572	11,440	5	3	0	Commenced work with shorter shaft, new angle wheels, &c.
h	15	3	0	0	15	5				41	6	3	2	6	0	43	12	3	16	2	5	59	14	8	10	668	13,360	4	7	0	
h	15	3	0	0	15	5				44	10	6	2	6	0	47	0	6	16	2	5	63	2	11	10	720	14,400	4	6	0	
h	15	3	0	0	15	5				39	5	6	2	6	0	41	11	6	16	2	5	57	13	11	10	760	15,200	3	12	0	
h	15	3	0	0	15	5				39	1	3	2	6	0	41	7	3	16	2	5	57	9	8	10	736	14,720	3	15	0	Stopped work to alter roads from single to double on the slopes.

April, 1873.

h	16	5	9	2	1	3	0	11	9	30	13	0	2	6	7	33	3	7	19	2	9	52	6	4	10	800	16,000	3	4	4	
h	16	5	9	2	1	3	0	11	9	32	13	6	2	6	7	35	4	1	19	2	9	54	6	10	10	812	16,240	3	5	7	
h	..	..	..	..	..	..	..	..	..	..	..	..	2	6	7	2	6	7	..	..	..	2	6	7	..	..	..	..	..	..	
h	16	5	9	2	1	3	0	11	9	30	13	6	2	6	7	33	4	1	19	2	9	52	6	10	10	788	15,760	3	5	2	
h	..	..	..	..	..	..	..	..	..	3	5	0	2	6	7	5	11	7	..	..	..	5	11	7	..	..	..	..	..	..	
h	16	5	9	2	1	3	0	11	9	33	0	9	2	6	7	35	7	6	19	2	9	54	10	1	10	884	17,680	3	1	5	
h	16	5	9	2	1	3	0	11	9	32	13	6	2	6	7	35	4	1	19	2	9	54	6	10	10	788	15,760	3	1	5	
h	16	5	9	2	1	3	0	11	9	35	3	9	2	6	7	37	10	4	19	2	9	56	13	1	10	788	15,760	3	9	8	
h	16	5	9	2	1	3	0	11	9	36	3	6	2	6	7	38	10	1	19	2	9	57	12	10	10	804	16,080	3	9	6	
h	16	5	9	2	1	3	0	11	9	36	3	6	2	6	7	38	10	1	19	2	9	57	12	10	10	800	16,000	3	11	4	
h	16	5	9	2	1	3	0	11	9	37	12	0	2	6	7	40	2	7	19	2	9	59	5	4	10	740	14,800	3	14	4	
h	16	5	9	2	1	3	0	11	9	36	2	0	2	6	7	38	8	7	19	2	9	57	11	4	10	740	14,800	3	14	4	
h	..	..	..	..	..	..	..	..	..	5	13	9	2	6	7	8	4	4	..	..	..	8	4	4	..	..	..	..	..	..	Working only ½ day. Shaft to machine broke.
st	12	0	3	2	1	3	0	11	9	36	3	0	2	6	7	38	9	7	14	1	6	52	11	1	5	408	8,160	6	7	0	

J. D. D.

Report by LIEUT. J. F. MILLER, *Assist. Engineer, 2nd Division, Sirhind Canal.*

Dated 9th April, 1873.

Experiment No. 5. Mr. Cheyne's System.—An engine lift on the "long incline" system was erected at the 18th mile, for the purpose of taking out the excavation from 17th mile 3,500 to 18th mile 1,500, a length of 30 chains. The general arrangement of inclines is shown in *Plate* XXVIII., from which will be seen that there is a considerable portion of work contained between the bottoms of inclines which would have to be taken out by "back handing." During the time the lift was running, only that part of excavation in front of the inclines was worked on, so no data have been arrived at as to cost of work in "rake," or best method of carrying it out. The total height to which earth was raised was 40·31 feet.

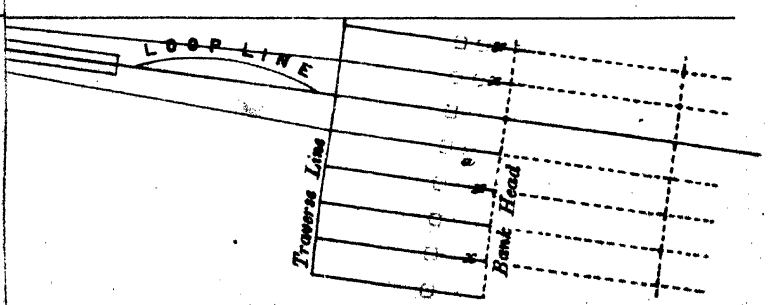
The *motive power* was a 12 H. P. portable engine by Ruston and Proctor of Leeds, running at 120 revolutions per minute, with a working pressure 55 lbs. per square inch in boiler. Power was transmitted to the winding machine by a seven-inch double vulcanized India rubber belt; the drum on engine shaft being the same diameter as that on machine counter shaft, viz., 3 feet.

The *rope* used was of galvanized iron wire, 1⅛-inch circumference. *This was wound on machine drums*, and passed off them round angle wheels, (*Plate* XXIX.,) down the inclines, being supported at intervals of 10 feet by small rollers. Both winding drums and angle wheels were found too small in practice, causing damage to the rope by overbending it. The diameter of all drums and angle wheels used should not be less than 140 times the diameter of the rope, according to Rankine. By this allowance, the drums and wheels should have been 5 feet 10 inches diameter.

Wagons used carried 25 cubic feet; they were of the ordinary type adopted on the canal.

Traverses.—The wheels of these were found to wear a great deal, owing to the tire being of small diameter, and having much running, as there were too few traverses on the work for the number of wagons to be traversed. A good deal of wear also took place at the wooden axle boxes, allowing the traverse frame to fall below its proper level. These difficulties might be overcome by having the wheels cast with a chilled tire, and replacing the wooden tap box of axle bearing by a cast-iron one. In fact, it would be better if iron of suitable form were substituted for all wood hitherto employed in the frame.

L GROUND.



Rails of various sections were used from "T" rails of 28 lbs. per yard, to "bridge" rails of a little under 12 lbs. per yard. The latter were found too light for the work.

Sleepers of "kíkar" (*Acacia Arabica*) and "phuláhi" (*Acacia Modesta*) 4·5 × 4 × 4 inches laid at 3·5 feet intervals for the "T" rails, and at 2 feet spaces for the light "bridge" section.

These sleepers were lasting and cheap; but being of such hard wood, it was impossible to drive the dog spikes into them without previously boring.

General Arrangements, (*vide Plate* XXVIII.)—There are three sets of 10 wagons each required for either incline. These are coloured red, green and blue. At the moment represented in the drawing, the trains marked *a*, *a*, *a*, on inclines on left hand side of drawing, are employed as follows:—The green train has just been run into gullets *x*, *x*, by traverses, to be filled, while train coloured blue is being hauled up the incline. On reaching the platform at top, and clearing the empties (coloured red) standing on a loop line, the latter train will be despatched down incline, and run on to the loop line, remaining there till green train, now filling, is made up on the main line. The blue train *a*, in the meantime would be at the tip heads.

On incline on right hand side of drawing, a train of empties (blue *b*) is running down to replace at the gullets the green train *b*, which is standing ready to ascend. At the same time the third (red) train of this series is getting tipped, and will be brought back empty on to the loop line by the time the next train of fulls arrives from below.

The portion of plan coloured pink shows the embankment which must be prepared previous to starting engine work. The dark portion is the cutting which has similarly to be prepared.

Observations extended over a period of eight months, give a mean rate of Rs. 3-12-9 per 1,000 cubic feet for work performed by this engine incline. This rate includes pay of all workpeople employed; also engine charges for fuel, attendance and small stores.

ADDENDA TO ABOVE.

The greatest number of wagons raised in one day was 720, being due to 40 trains of 10 wagons each from one incline, and a like number of trains of eight wagons each from the other incline; eight wagons per train were employed on one side, owing to a paucity of rolling-stock. There were only eight traverses used on the whole system, *i. e.*, two traverses at each

line giving on to the gullets, and two at each line giving on to tip heads. Had there been three traverses at each of these points, there is little doubt the work would have been accelerated.

The disposition of men was as follows :—

5 men at each gullet getting and filling.
4 „ traverse shunting wagons.
1 man to each wagon of train who received it at top of incline, and ran it to traverse line for distribution to tip heads. This party also brought back empties to head of incline and despatched them.
2 men at each tip head.
1 boy „ „ switch.
1 „ to „ incline who rolls on train, and casts off rope.
1 „ at „ signal post, of whom there were three ; that is, one in either pit, and one at top of bank in front of engine.
4 men at winding machine, working brakes, clutches and setting on rope to drums.
3 boys greasing wagons, angle wheels, rollers and traverse bearings.
1 Engine driver.
1 Fireman.
4 Bhistís supplying water to engine and coolies.

The mean quantity of hard wood-fuel consumed per diem was 14 maunds, and of coal, 9 maunds.

The percentages of various charges, making up the aggregate rate of Rs. 3-12-9 per 1,000 cubic feet, were as follow :—

i.	Engine charges, including tending winding machine, ..	21·09
ii.	Plate-laying and petty repairs to rolling-stock, pay of signal and pointsmen and chaukídár, ...	13·56
iii.	Labor in getting, filling, running and tipping ; also pay of native gangers, ...	65·35
	Total ..	100·00

The above was from results when coal was used, the proportionate cost of which, on the quantity burnt per diem, is to the cost of wood-fuel as 13·5 : 4·2.

J. F. M.

Report by MAJOR R. HOME, R.E., *Supdg. Engineer, Sirhind Canal.*

Dated 2nd September, 1873.

I propose briefly to review the results obtained by the experiments in the following order :—

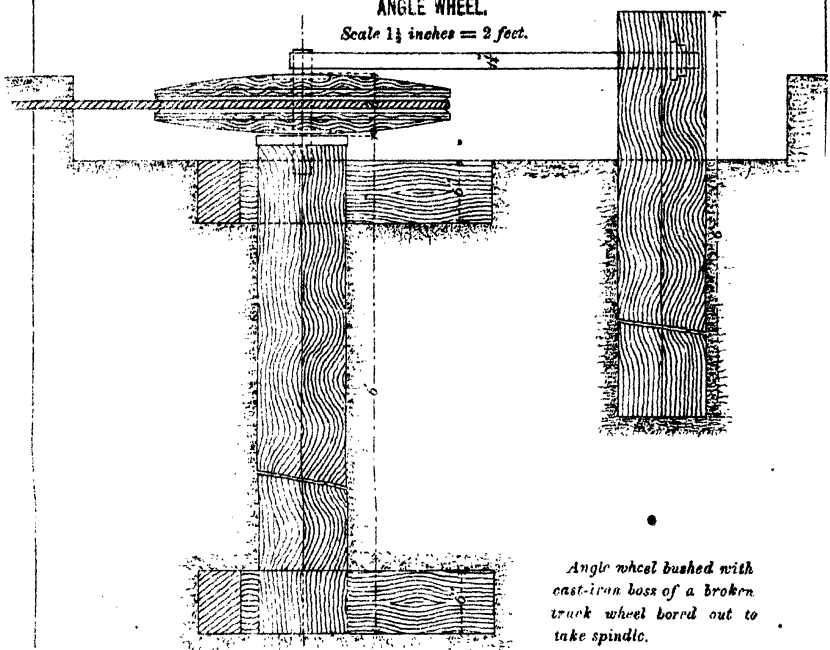
1. Barrows on rails or plank roads, empties assisting to bring up fulls.
2. Revolving beam with buckets and barrows.

EARTHWORK EXPERIMENTS ON SIRHIND CANAL.

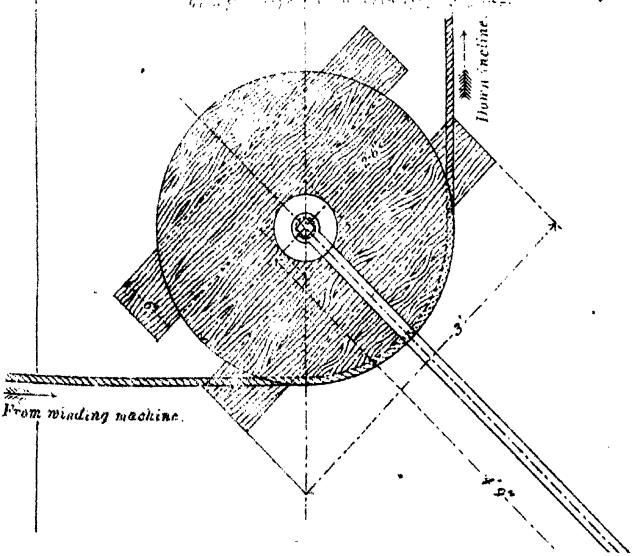
EXPERIMENT No. 5—MR. CHEYNE'S SYSTEM.

ANGLE WHEEL.

Scale 1½ inches = 2 feet.



Angle wheel bushed with cast-iron boss of a broken truck wheel bored out to take spindle.



3. 5-cubic-feet wagons on rails, empties assisting to bring up fulls.
4. 25-cubic-feet wagons on rails brought to bank by stationary engine winding wire ropes on drums (Mr. Derry's system).
5. Similar to No. 4 (Mr. Cheyne's system).

No. 1. *Barrows on rails or plank roads.*—This is described in Mr. Derry's report, as the first experiment to compete with the coolie and basket. I did not see it at work myself, but from Mr. Derry's report, it appears that, with an endless rope passing round two grooved wheels of 4 feet diameter, placed at the head and foot of the incline, both empty and full barrows being attached to swells on the rope, a strong man wheeling an empty barrow down the slope of 1 in 3, was able to bring up the full barrow (which was guided by a man walking between the handles in the usual manner) with very satisfactory results. This method was abandoned—

1*st.* On account of the expense of planks required to make a smooth and permanent road.

2*nd.* Because the ordinary coolie was not strong enough to manage a wheel-barrow in such a position.

A modification of the above was tried, with a rail for road and a grooved wheel to the barrow; the wheel was also set askew, so that the man guiding, might walk clear of the rail, but with much the same result.

Mr. Derry further states that, with a greater height of lift than 23 feet, the rope becomes unmanageable; and looking at the small quantity brought to bank by each barrow, it is evident that an enormous number of barrow runs, and consequently plant, would be necessary to make any impression on such a channel as the Sirhind Canal.

For a dock or tank, or any excavation of 10 to 20 feet depth in wet or dry soil, where the area is of limited extent, and time an object, or labor very scarce, I have no doubt that either of the forms of barrow runs experimented on by Mr. Derry, might be advantageously employed.

No. 2. *Revolving beam with bucket or barrows.*—This system is described by Mr. Derry in his report, pages 152 and 153, at some length; but, as in No. 1 Experiment, he has given no actual comparison of cost of labor and plant, with that of coolie and basket at similar depths, and for the same reason, I believe, in both cases, viz., that the failure of the experiment, on a large scale became apparent,

Plate XXIII.

before the apparatus had been at work long enough to test its durability, and consequently the proportion of its cost due to the unit of work. The plan, &c., fully elucidate the system, which may be shortly described as a framed beam pivoted by its centre at right angles to a support fixed in the ground at an angle of 45°. The beam has a hook or slings, and a swinging bar at either end. When a man is seated on the bar at upper end of the beam, and the beam is set in motion, his weight causes a receptacle full of earth attached to the hook or slings at the lower end to change places with him; he then walks up the slope, and is ready for another trip. The vertical height to which the earth was raised by one of the beams experimented on was 15 feet. I never saw any experiments with two beams, as they were made before I returned from England; but with the single beam and barrow, the main difficulty apparently was to get a native heavy enough to counterbalance the load at the lower end of the beam. I can quite understand the difficulty experienced by Mr. Derry in getting natives to shift a loaded skip weighing 270 lbs., or nearly 3½ maunds from one frame to the other.

The cost of the beams, &c., for one system of two beams for a 30-feet lift, would be—

	Rs.
Cost of two revolving beams, ...	90
„ intermediate beam for shifting skips, ...	5
„ four skips, ...	20
„ two trollies for transporting skips, ...	15
Total cost of each revolving lift, ...	130

In Mr. Derry's final remarks, that this plan might be economically used in raising water to a height of, say, 15 feet, for irrigation purposes, I quite concur.

No. 3. *Wagons of* 5*-cubic-feet contents, empties assisting to bring up fulls.*—This system is described by Mr. Derry so fully, that it leaves me little to say on the subject. It was first of all tried on the 17th mile at Khirri, under Mr. Derry's personal supervision, and succeeded so well, that it is now being worked on a more extended scale at the Ráipur hill in the 12th mile, where the peculiar circumstances of the ground render the use of mechanical appliances advisable.

Plate XXIV.

The wagons used are of 5-cubic-feet contents, but in reality hold 4·5 cubic feet of earth measured in the solid; they are made of wood with cast-iron wheels of 1·25 feet diameter, which run on a light railway of

1·50 gauge in each incline. There are two lines of rail on a slope of 1 in 3, and 5 feet apart centre to centre. A wheel of 5 feet diameter, pivoted on a post at the head of the slope, in such a position as to have its surface parallel to the plane of the rails, carries in a groove a wire rope, to one end of which is attached an empty wagon at the top on one line of rail, and to the other a full wagon at the bottom of the slope on the other road; these men applying their weight and powers, push down the empty, and bring up the full wagon. A 6-throw turn-table of cast-iron is placed clear of the top and bottom of the slope, and by their means, the wagons are turned in the desired direction, either on bank or in bed. Mr. Derry states that he has actually raised 800 wagons (3,600 cubic feet) a total height of 40 feet with his apparatus in a day of 10 hours; and has worked at the rate of 1,200 wagons (5,400 cubic feet), or two wagons per minute; the usual rate of working with ordinary men at this depth appears, however, to be one wagon per minute, or 600 wagons per day (2,700 cubic feet).

On page 157, Mr. Derry speaks of the advantages to be derived by the use of steam to drive the wheel at the head of the slope; if any power were to be employed for that purpose, I would recommend bullock-power in place of steam. By increasing the number of bullocks, an amount of power could be obtained sufficient to drive the wheel with the load of one wagon, or even two, at any speed compatible with safety, and with these advantages over steam—

1*st*. The first cost of a bullock-wheel is less than that of an engine.

2*nd*. That if a bullock is disabled, it is easily replaced, whilst if the engine gets out of order, the work is stopped until the necessary repairs are executed.

On the work at present in hand at the Ráipur hill, where the ground requires that all the spoil should be thrown on one bank, and the position of the village of Ráipur renders the lead on bank exceptionably long, the 5-cubic-feet wagons have been economised, by using 25-cubic-feet wagons on the bank into which the smaller wagons tip when they arrive at the head of the slope. As two men can easily push a loaded 25-cubic-feet wagon on a moderate slope (of, say, 1 in 200) to the tip head, and there are plenty of these wagons in store, this method economises both labor and materials.

The following statements from Mr. Hammer (*Exec. Engineer*)—em-

bodying further information,—give details on the subject of cost. The first statement shows the cost of raising earth 52 feet at Khirri, by 5-cubic-feet wagons alone, and the second is a statement of cost of work performed by combined 25-cubic-feet and 5-cubic-feet wagons on the 22-feet lift at Ráipur hill; cost of the plant is derived from the registers of the Division—its life is necessarily in part estimated; labor and repairs are obtained from the daily reports; and the statements give, I believe, as accurate information of the cost of the work as can be obtained. A comparison of these two statements shows, as might be expected, that the system works better with longer lead, and that the employment of the larger wagons for the long lead on spoil is a decided saving.

I agree with Mr. Derry in his opinion, that this system is not suited for extended application. At Ráipur, the ground was found to be too cramped to admit of the employment of the locomotive tram, which we first thought of using, and the system now at work seems eminently suited to this short piece of heavy excavation. On a length of several miles, the multiplication of plant, and of its repairs, together with the careful supervision required to keep both plant and roads in good order, and the excavation systematically performed, would be a bar to its use in India under ordinary circumstances.

No. 4. *25-cubic-feet wagons on rails brought to bank by stationary engine (Mr. Derry's system).*—As this system has from first to last been elaborated by Mr. Derry, and the experiment carried out under his personal supervision, nothing would be gained by my going into details of construction, &c., which are fully set forth in the original report.

Plates XXV., XXVI., XXVII.

I have stated in the foot notes, the points on which I differ with Mr. Derry, and have corrected what appeared to be mistakes, and supplied omissions.

The *Plates* show the system better than any written description. The reasons for preferring it to the long inclines, which were proposed in the report on the estimate for the Sirhind Canal, and of which No. 5 Experiment is a modification, are fully detailed by Mr. Derry, and I concur in the advantages which he claims for it.

The difficulties encountered in elaborating the system have been numerous, and the alterations of the plant and roads which they necessitated have been tedious and expensive. I think that Mr. Derry's description

(page 167, *et seq.*) of the entire system, as he would propose to erect it, after the experience gained on the lift at Khirri, is sound and good, and that all the weak points of the experimental lift have been met and remedied. The more powerful engine, the iron wagons of less capability and with larger wheels, the narrower gauge and cast-iron turn-tables, are all decided improvements; but I do not think that there will be any necessity with the narrower gauge to double the line on the slopes, as the wagons will not have the same tendency to run off the line at the crossings as they had with the broad gauge. The present experiments were carried out with rails of all sections and weights; the turn-tables were, many of them, roughly made; the wagons originally designed for the long incline system were not stiff enough in the framing for the steep inclines; there was no proper apparatus for bending the rails; the alterations in the drums, pulleys, &c., were made so as to utilize the materials at hand, and were therefore necessarily imperfect; the wire rope, manufactured in this country, was not as good as was expected; and the engine was not powerful enough for the work, so it is not to be wondered at if the results obtained did not quite answer expectation; but I have little doubt that, under suitable conditions of depth of excavation and magnitude of operations with plant manufactured for the purpose in England, good and economical results would be obtained from the employment of this system of engine lift.

In the foot note, page 170, I have expressed my doubt of the results which Mr. Derry expects to obtain with a perfect system, for the following reasons:—The number of wagons raised with the four inclines at Khirri, was eight in four minutes, when everything was working smoothly and well; with the full system of eight inclines, the number of wagons would, of course, be doubled, giving four wagons in one minute.

Mr. Derry, on page 170, bases his calculations on an estimate of four wagons in three-fourths of a minute, hoping, as I suppose, to obtain this favorable result from the greater speed of the more powerful engine, and also as an average for the three lifts; but I would submit that where more inclines are at work, the chances of delay are increased. I therefore think, that it would be advisable to put the greater speed of haulage, &c., against the increased chances of delay, and to adhere to the results already obtained of four wagons in one minute. This reduces the number of wagons raised per day of 10 hours to 2,400, and the cubic feet to 48,000.

I have shown on page 175, how this reduced out-turn of work will affect the comparison of engine and coolie work in the 10 miles length of canal on which Mr. Derry has exemplified the advantages to be obtained by the use of his system.

Mr. Derry has appended to his report tabular statements, showing the cost and quantity of work performed by his experimental lift during the months, when it may be said to have been in full operation, and has commented on the results obtained in page 173; the whole gives a history of the experiment, which requires no comment.

No. 5. *25-cubic-feet wagons on rails brought to bank by stationary engins winding wire ropes on drums (Mr. Cheyne's system).*—A report is appended with drawings, by Lieut. J. F. Miller, Assistant Engineer, 2nd Division, Sirhind Canal, who was in charge of the experiment in this Division. The system is a modification by Mr. Cheyne of that proposed in the report on the estimate for the canal. It was supposed on further consideration, that the original system would fail in working for the following reasons:—

1*st.* The curves were too sharp for the wagons to run round with safety.

2*nd.* The wagons linked together in front of the working face, were in an unfavorable position for filling.

3*rd.* The difficulty of moving the rail in front of the working face forward by slewing, on account of its oblique position, and the curves of which it was composed.

4*th.* The difficulty of lengthening the rope as the work advanced further from the foot of the incline.

There may have been other reasons with which I am not acquainted, as the scheme was abandoned during my absence from the canal.

The drawings and explanation given by Lieut. Miller, sufficiently elucidate the working of the system, and the postscript which he has appended, gives an average of Rs. 3-12-9 per 1,000 cubic feet of the work performed by it. Doubtless, during the time that this system was at work, many hindrances occurred, which raised the rate of the work; and I think that, taking these into consideration, Rs. 3 per 1,000 cubic feet, may be estimated as a fair working rate for labor and sundries and petty repairs. I have not gone into the question of cost of plant for this system, as its chances of success appeared small for the reasons stated further

on; but the plant is at least as costly as that required for Mr. Derry's system. The work performed was only the straightforward work beyond the foot of the inclines; and at the time when the experiment was stopped, I had under consideration two or three different plans for taking out the excavation between the feet of the inclines, none of which appeared to me satisfactory, nor did I see how the earth could be removed without great waste, both of time and money. This is, in fact, the great blot in the system.

The point which appears most worthy of remark in the working of the system, is the use of traverse carriages running on lines sunk below the level of the tramways. These traverse lines and carriages supplied the place of turn-tables, and, although roughly made, they did their work satisfactorily. They would appear to be suitable for work on the spoil, where the sunk traverse lines could be easily drained, but not fit for employment in the pit, where in wet weather they would of necessity be under water. I think that great praise is due to Lieut. Miller for the care and intelligence with which he supervised this experiment, whilst he was at the same time in charge of a considerable length of very heavy excavation crowded with famine laborers.

STATEMENT No. 1.

Statement showing cost of 1,000 cubic feet of earth put to spoil by 5-cubic-feet wagons on a single incline at Khirri in 17th mile; depth of digging 35·5 feet; height of spoil 17·0 feet; total lift 52·5 feet; extreme lead on spoil 350 feet; ditto in bed 150 feet; length of incline 170 feet; number of wagons raised per diem 365, each wagon containing 4·5 cubic feet of solid excavation; brought to spoil per day 2,542 cubic feet for 25 days in the month; soil, sand.

Description.	Number or weight.	Rate.	Per	Cost.			Cost per 1,000 cubic feet.			Remarks.
		RS. A. P.		RS.	A.	P.	RS.	A.	P.	
PLANT.										
Life three years.										
Cast-iron turn-tables, ..	2	69 0 0	Each.	138	0	0				Mr. Hammer states that he can get men to do this work by contract for Rs. 5 per 1,000 cubic feet; but I am of opinion that the men are willing to take the lower rate sooner than go to the 1st Division.
Rails (12 lbs.), ..	Mds. 123	8 0 0	Md.	984	0	0				
5-cubic-feet wagons, ..	14	63 0 0	Each.	882	0	0				
Shovels and picks, ..	16	..	..	50	0	0	0	14	4	
Life two years.										
Wheel for rope, ..	1	15 0 0	Each.	15	0	0	0	0	2	
Life one year.										
Preparing ground, &c., ..	L. F. 250	13 0 0	100	32	8	0				
Sleepers, ..	No. 418	0 2 0	Each.	52	4	0				
Laying road, ..	L. F. 250	15 0 0	100	37	8	0	0	2	7	
Life two months.										
Wire rope, ..	„ 200	15 0 0	100	30	0	0	0	3	9	
Labor.										
Getting, ..	..	..	Day.	1	7	0				
Raising, ..	..	..	..	3	12	9				
Tipping, ..	..	..	..	1	15	6				
Mistri, mate, &c., ..	..	..	..	1	3	6	1	4	10	
Repairs.	..	..	Diem.	0	10	0	3	8	11	
Total cost, labor, plant, repairs, &c., per 1,000 cubic feet, ..	..	..	..	..	..	..	4	13	9	
Bonus paid on wagons when more than 500 per day, ..	65	0 1 0	5	0	13	0	0	5	1	
Grand Total, ..	..	..	..	..	..	..	5	2	10	
The rates for labor are—										
Men, 1st class, Rs. 0-4-0 per diem, ..										
Men, 2nd class, Rs. 0-3-6 per diem, ..										
Boys, Rs. 0-3-0 per diem,										

STATEMENT No. 2.

Statement showing cost of 1,000 cubic feet of earth put to spoil by the system of inclines, worked with 5-cubic-feet wagons in bed on slope; and 25-cubic-feet wagons on spoil at Rdipur in the 12th mile; total lift 22 feet; lead on spoil 650 feet; ditto in bed 200 feet; length of incline 80 feet; four inclines are served by one double line with four tips on bank. The quantities are reduced to the unit of one incline, on which 610·5 cubic feet wagons, or 2,750 cubic feet of earth, are brought to bank per diem for 25 days per month.

Description.	Number or weight.	Rate.	Per	Cost.			Cost per 1,000 cubic feet.			Remarks.
		RS. A. P.		RS.	A.	P.	RS.	A.	P.	
PLANT.										
Life three years.										
Cast-iron turn-tables, ..	2	69 0 0	Each,	138	0	0	..	..	..	The total depth of excavation at Rdipur hill is nearly 50 feet, and, with the longlead on bank and in bed, it is likely that the system now employed there will pay.
Rails (12 lbs.), ..	Mds. 135	8 0 0	Md.,	1,080	0	0	..	..	..	
5-cubic-feet wagons, ..	12	63 0 0	Each,	756	0	0	..	..	..	
25-cubic-feet wagons, ..	2	95 0 0	Each,	190	0	0	..	..	..	
Shovels, picks, &c., ..	16	..	..	50	0	0	0	14	4	
Life two years.										
Wheel for rope, ..	1	15 0 0	Each,	15	0	0	0	0	2	Mr. Derry in his report, states that this work would cost by petty contract at 22 feet depth, Rs. 7, and at 50 feet, Rs. 9, per 1,000 cubic feet.
Life one year.										
Preparing ground, &c.,	L. F. 150	13 0 0	100	19	8	0	..	..	..	
Sleepers, ..	No. 320	0 2 0	Each,	40	0	0	..	..	..	
Do., ..	„ 132	0 4 0	Each,	33	0	0	..	..	..	
Laying road, ..	L. F. 550	15 0 0	100	82	8	0	0	3	5	
Life two months.										
Wire rope, ..	L. F. 100	15 0 0	100	15	0	0	0	1	9	There is no bonus system on this work.
Labor.										
On inclines and in bed, per day, ..	..	..	..	15	3	6	..	..	..	
On spoil, per day, ..	..	..	..	1	15	3	..	..	..	
Mistri, mate, &c., per day,	..	..	..	1	8	0	..	..	..	
Shop repairs, &c., per day,	..	..	..	0	10	0	3	6	1	
The rates of labor are—										
Men, 1st class, 0-4-0, ..										
„ 2nd „ 0-3-6, ..										
Boys, 0-3-0, ..										
Total cost of 1,000 cubic feet, ..	..	..	..	..	..	..	4	9	9	

R. H.

Memorandum by COL. J. CROFTON, R.E., *Chief Engineer, Irrigation Works, Punjab.*

Camp, 27th January, 1874.

Seven different systems of working with mechanical appliances have now been tried, viz.:—

No. 1. Barrows running on rails or planks laid on inclined road.

No. 2. Revolving beam with wooden buckets, skips, or barrows. Spoil run out by small wagons or barrows.

No. 3. Wagons of 5-cubic-feet capacity on rails laid on incline. Empties assisting to bring up the full wagons.

No. 4. Wagons of 25-cubic-feet capacity on rails laid on steep incline, drawn up to top of spoil bank by rope round a drum worked by stationary steam engine. Spoil spread by same wagons on rails. (Mr. Derry's system).

No. 5. Combination of Nos. 3 and 4, but without steam engine. Spoil raised to top of spoil bank by 5-cubic-feet wagons, tipped into 25-cubic-feet wagons, by which it is run out and distributed.

No. 6. Similar to No. 4, but on long incline. (Mr. Cheyne's system).

No. 7. Wagons on rails on long incline drawn by locomotive engine.

Nos. 5 and 7 are now in operation, the rest having been abandoned for reasons given in the papers appended.

The following is a brief summary of the several modes of working and the results.

No. 1. An endless rope was passed round two grooved wheels fixed, one at the top, the other at the foot of an incline of 1 in 3. On this rope were swells or knots at intervals, to which, on one side full barrows, on the other empty barrows, were attached, running at first on a planked road; the barrows were guided by men; a strong coolie wheeling an empty barrow down being able to bring up a full one.

This system was abandoned—

1*st.* On account of the cost of planking the road for the barrows.

2*nd.* Because the *ordinary* native workmen were not strong enough to manage barrows either on the planked road, or on rail (in which case the barrow wheels were grooved).

3*rd.* On account of the quantity of plant required for a work of such magnitude as this canal.

On a less extensive work, where it would not be necessary to shift the roads so constantly, the system would probably give economical results. The experience gained showed, that with a greater lift than 23 feet, the rope became unmanageable.

Cost of working on this system is not given.

No. 2. A beam 22 feet long revolved on a pivot fixed in an incline of 1 in 1. A bucket, barrow, or skip, full of earth was attached to the lower end, and at the upper an empty skip and man standing on a cross bar (represented in *Plate* XXIII.), overbalanced the full skip, thus causing the beam to revolve, and raising the latter to a height of about 15 feet.

This was abandoned, on account of the difficulty of getting a native of sufficient weight to overbalance the beam, and also the inapplicability of the method to work on a large scale, or where the lift was greater than 15 feet.

No detail of cost of working is given, as the system was soon abandoned.

No. 3. Wagons of 5-cubic-feet capacity on cast-iron wheels 1½ feet diameter, running on railway of 1½ feet gauge, were attached to a rope, on an incline of 1 in 3, passing round a drum fixed at top of the slope, as represented in *Plate* XXIV., the empty wagons pushed down by coolies bringing up the full ones.

This system gave very fair results, where the extent of work was not great as happened to be the case where it was tried.

Instead of employing men in moving the wagons on the incline, it is suggested that steam or other power applied to turn the wheel at the top of the incline, round which, and a drum at the foot, an endless rope would pass to which the wagons could be attached, would give more economical results.

Major Home gives the cost of working by this method, including share of plant, &c., as Rs. 5-2-10 per 1,000 cubic feet, where—

Total lift was	52·5 feet.
Total length of lead	661 „

His figures are taken from the schedules of actual expenditure on the work. The labor from the day-books, and the cost of plant as made up in the Canal shops, or purchased as shown by the "Register of Works;" the length of time each description of plant is likely to last is estimated. This system was worked out with great care by Mr. Derry, as will be seen by the detailed reports. His improvements in the appliances, especially

the cast iron turn-tables, have tended materially to the success of the experiment.

It is not, however, suited to any very great length of excavation, on account of the constant transfer of rails and machines as the work progresses.

No. 4. In this system, wagons of 25-cubic-feet capacity were drawn up an incline of 1 in 2½, by wire rope on a drum worked by a stationary steam engine. This also was worked out from first to last with great care by Mr. Derry, and numerous improvements introduced as suggested by experience during the course of the trial, but owing to want of proper plant, the system has not had a fair trial. I quite agree with Major Home, in thinking that with mechanical appliances specially made up for the purpose, and under suitable conditions of depth of excavation, and extent of work, this system would give very good results; better, so far as the experience on this Canal goes, than those obtainable on the long incline system described below as Experiment No. 6.

The monthly abstracts of expenditure appended to Mr. Derry's report, give the actual cost of working by this method, not including share of original cost of plant.

For the following months, the averages per 1,000 cubic feet, for a lift of 50 feet, and a lead of about 500 feet, were—

	RS.	AS.	P.
November, 1872, ...	4	1	4
December „	3	6	6
January, 1873, ...	3	4	5
February „	3	13	4
March „	4	5	0
April „	3	12	0

These rates of course are much higher than would have been the case with proper plant, and the appliances which experience proved to be necessary.

No. 5. The spoil in this experiment was raised to top of bank by the 5-cubic-feet wagons, as described in No. 3, and tipped into 25-cubic-feet wagons, by which it was distributed on the spoil bank. This was found to be the most economical mode where the lead was long, and is still in operation with very satisfactory results on the only remaining piece of deep cutting in the 2nd Division of the canal. Steam power is not employed, men only being employed in moving the wagons.

Major Home gives a statement of results calculated, as in experiment No. 3, from the actual expenditure, and the cost of the plant—

The total lift was	22 feet.
Total length of lead	927 „

The average rate per 1,000 cubic feet thus obtained was Rs. 4-9-9.

No. 6. Wagons and motive power same as in No. 4, but the slope of the incline 1 in 20. It was a modification by Mr. Cheyne, then Executive Engineer of the 1st Division, of the system proposed in the original estimate for the Canal. It was worked in the 2nd Division also, alongside the steep incline system elaborated by Mr. Derry. Lieut. Miller, the Assistant Engineer in charge of the experiment, gives the details, which were worked out by him with great care. The lift in this case was 40 feet, and the expenditure during eight months on labor and sundries, not including share of plant, averaged Rs. 3-12-9 per 1,000 cubic feet.

Similar difficulties as in experiment No. 4 were experienced in the want of proper appliances, and, on the whole, it does not seem to have been so successful as No. 4.

One objection to it is the difficulty of removing the earth between the feet of the inclines.

One peculiar feature in the system introduced by Lieut. Miller, was the use of traverse carriages and lines of rail instead of turn-tables. On the spoil banks where accumulations of drainage water could be carried off, the traverse system answers well, but is not suited to the bed of the channel, where the water, which collects in every hollow after a heavy fall of rain, cannot easily be run off.

An experiment on this system in the 1st Division, where it was carried out by Mr. Cheyne himself, is alluded to by Major Home. It seems to have failed there, chiefly on account of the height at which the spring-level stood, and the difficulty of carrying off this water, the drainage cuts for unwatering the excavation not having been then completed. The portion on which this trial was made, will be taken out by locomotive and wagons.

One or two other methods, not alluded to in the foregoing papers, were tried by Mr. Cheyne in the 1st Division, but were abandoned after a short experience, the results proving clearly that they were unsuited to the work.

In one experiment, the spoil was raised from the excavation to the ground level in skips, containing one cubic foot, by a balance beam, similar

to that in common use for raising water ("*dhenkli*"), these were emptied into small wagons running on a narrow gauge railway, and pushed out to bank by men.

Wagons on incline drawn by horses were also tried, but did not answer.

No. 7. This system had only been started shortly before the date of Major Home's report. The results will be communicated as soon as sufficient time has elapsed to admit of a fair judgment being formed. The gauge of the tram roads is the same as that of the railway along the canal, so that all rolling stock can be used on either one or the other. I saw it working on the excavation near the head in November last, and again a few days ago. It is intended to apply it to the excavation of the first two miles of the canal, and here it bids fair to be the best and most economical mode of working.

This report would be incomplete without a comparison of the rates of excavation by ordinary manual labor, which are as follow :—

When Mr. Derry commenced his experiments with mechanical appliances in the 2nd Division, (comprising the section from the 12th to 39th mile inclusive,) the actual contract rates were—

For Lead about 150 feet Lift „ 3 „	... ...	Rs. 2-4-0 per 1,000 cubic feet.
For Lead „ 200 „ Lift „ 45 „	... ...	„ 5-8-0 „ „ „

In the deep excavation at Raipur in the 12th mile, where the mechanical system No. 5 described above, is at work, excavation is also now being done on contract by manual labor at the following rates :—

For Lift of about 33 feet Lead of „ 318 „	... ...	Rs. 4 per 1,000 cubic feet.
For Lift of „ 48 „ Lead of „ 400 „	... ...	„ 5 „ „ „

The rates obtained from the working of the mechanical arrangements, (Experiments 3 and 5,) it will be seen compare very favorably with these.

It has been found, by experience on this Canal, that the increase of rate for 1 foot of lift is equivalent to that for 6 feet of lead.

One reason is, I think clearly taught by these experiments, that where mechanical appliances are to be used for excavation, it is very false economy to employ make-shifts. The plant should be designed and specially manufactured for the purpose. The engine lifts especially (Experiments 4 and 6) as stated above, never had a fair chance of succeeding, owing to the want of properly made machinery and appliances.

J. C.

No. CLIX.

DELHI MEMORIAL MONUMENT.

[*Vide* Photograph, and Plates XXX., XXXI. and XXXII.]

By E. J. Martin, Esq., M.I.C.E. *and* A.R.I.B.A. *Exec. Engineer.*

As far back as 1859, a Committee was formed, composed of several of the Officers who were engaged in the Siege and Storming of Delhi, for the purpose of raising funds in India for the erection of a suitable Monument to the Memory of the British and Native Troops of the Delhi Field Force, who were killed in action, or died of wounds or disease during the siege operations, which, together with the minor actions fought, extended from the 30th May to the 20th September, 1857.

Competitive designs were invited, and several sets of plans were submitted. The Committee appointed to adjudicate upon the merits of the different designs awarded the premium to Mr. Edward J. Martin, at present Executive Engineer, Special Division, Tirhoot State Railway. Estimates were called for to accompany the designs, and the total cost of the work was not to exceed Rs 12,000.

As frequently happens in such cases, the Committee were of opinion that none of the designs submitted complied fully with the requirements of the competition, and ordered some alterations to be made in the selected design.

These modifications consisted of—

(*a*). The extension of the basement on plan, from a width of about 45 feet to a width of 80 feet, and an increase in its height from about 3 feet to nearly 20 feet.

(*b*). The provision of a vaulted octagonal chamber in the lower story with a cenotaph in the middle to contain special tablets.

The increased dimensions proposed involved an addition of over 100,000

cubic feet in the gross content of masonry in the basement alone: and, in order to assimilate the main shaft to the enlarged basement, and to provide room for the lower chamber and cenotaph, its size had to be considerably increased—the area of the lower portion from about 140 to 670 superficial feet, and the height above basement, from 60 feet to over 100 feet. It is, therefore, clear that the altered design, owing to the large increase in the quantity of work could not possibly have been carried out on the original estimate.

The estimated cost of the premiated design was Rs. 13,000, while that of the modified design amounted to over Rs. 40,000.

The work was commenced in February 1862, (the Committee being at the time in hopes of obtaining sufficient money by private contribution for the completion of the building,) and had to be suspended, for want of funds, in January 1863, the work actually executed being the construction of the enlarged basement, and the collection of sufficient sand stone, and other materials, to complete the monument.

A representation of the condition of the Memorial Fund was made by the Committee to his Excellency the Viceroy (Lord Lawrence), and a grant of money for the completion of the building was solicited. The Government of India promised to give a sum of Rs. 25,000 to aid in finishing the building, on an appropriate and approved design.

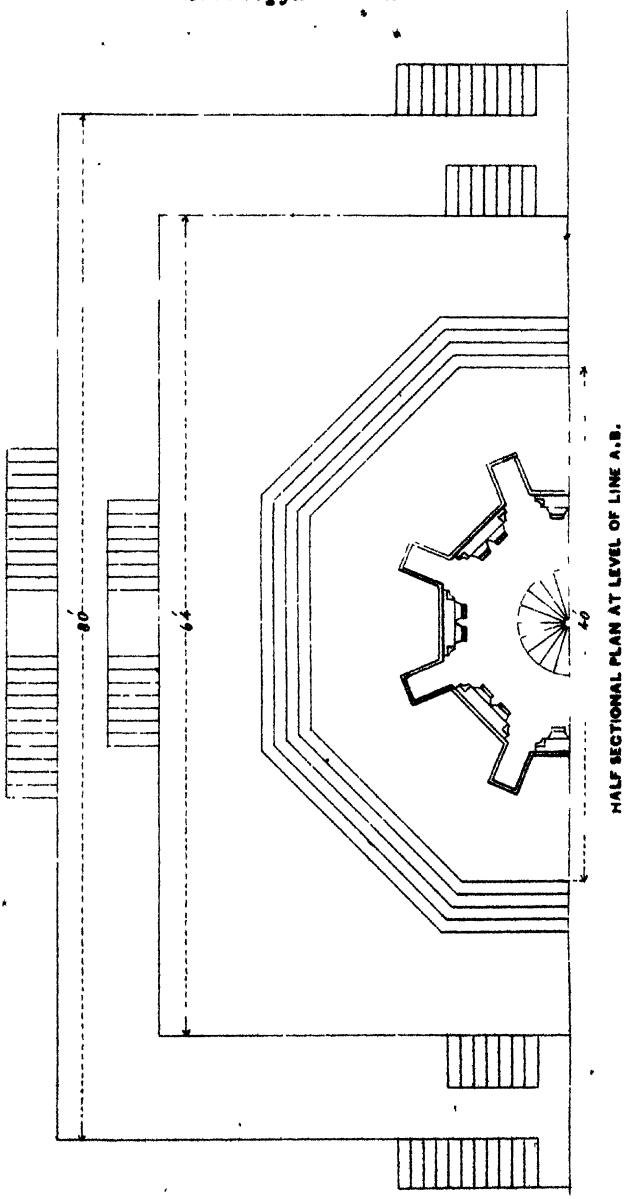
The author of the original premiated design was called upon to prepare fresh designs and estimate that should comply with the requirements of the Government of India.

The difficulty of adapting a superstructure costing a reasonable sum, to the extensive basement already constructed was admitted by the Supreme Government, and the design here illustrated was sanctioned by the Governor General, and has been completed well within the money limit assigned.

The monument has been erected near the end of the famous Delhi ridge, on an elevated and commanding site overlooking the Grand Trunk Road to Kurnaul and Amballa, and on the spot occupied by the advanced right battery during the siege. It consists of a Gothic octagonal tower, in the early English style of architecture, surmounted by a large white marble cross; there is a spiral staircase in the middle leading to a small chamber on top, from which an excellent view of Delhi and its environs is obtained. The tower is constructed of cut sandstone with rubble

DEHLI MEMORIAL MONUMENT.

Scale 13½ feet = 1 inch.



HALF SECTIONAL PLAN AT LEVEL OF LINE A.B.
(see Plate XXXI).

hearting; the whole of the carved and moulded work having been executed by Delhi workmen, from soapstone models prepared by the architect.

The basement is of coursed rubble masonry, with chiselled sandstone steps and quoins.

In the lower storey, the outer panels are filled with white marble tablets for inscriptions, divided by transoms and mullions, thus making each recess into one large and two small tablets; the latter are reserved for the names of the Officers of the Delhi Field Force who were killed in action or died of wounds, and other causes, during the siege operations; and the large tablets, commencing at the right hand side of the doorway, and working round the building, are allotted to the inscriptions as given in detail in the following lists:—

No. 1.

Inscription setting forth the object of the Memorial.

IN MEMORY

OF THE

OFFICERS AND SOLDIERS, BRITISH AND NATIVE,

OF THE DELHI FIELD FORCE,

WHO WERE KILLED IN ACTION, OR DIED

OF WOUNDS OR DISEASE,

BETWEEN 30TH MAY AND 20TH SEPTEMBER, 1857.

THIS MONUMENT HAS BEEN ERECTED

BY THE COMRADES WHO LAMENT THEIR LOSS,

AND BY THE GOVERNMENT THEY SERVED SO WELL.

Brigadier-General J. Nicholson, Commanding 4th Infantry Brigade.	Col. C. Chester, Adjt.-Genrl. of the Army. Captain C. W. Russell, 54th Native Infantry, Orderly Officer. Captain J. W. Delamain, 56th Native Infantry, Orderly Officer.

No. 2.

List of Regiments present at the siege of Delhi, between 30th May and 20th September, 1857.

Head-quarters, 1st Brigade, Horse Artillery.
1st, 2nd, 3rd, 4th and 5th Troops, Horse Artillery.
Head-quarters, 3rd Brigade, Horse Artillery.
2nd and 3rd Troops, 3rd Brigade, Horse Artillery.
3rd Company, 1st Battalion, Foot Artillery.
3rd Company, 3rd Battalion, Foot Artillery.
1st, 2nd and 4th Companies, 4th Battalion, Foot Artillery.
Head-quarters, 6th Battalion, Foot Artillery.
4th Company, 6th Battalion, Foot Artillery.
1st, 2nd and 3rd Companies, Sikh Artillery.
Detachment of Artillery Recruits.
Engineers.
6th Dragoon Guards.
9th Lancers.
4th Irregular Cavalry.
1st Punjab Cavalry.
2nd Punjab Cavalry.
5th Punjab Cavalry.
Hodson's Horse.
H. M.'s 8th Foot.
H. M.'s 52nd Light Infantry.
H. M.'s 60th Rifles.
H. M.'s 61st Foot.
H. M.'s 75th Foot.
1st Bengal Fusiliers.
2nd Bengal Fusiliers.
Sirmoor Battalion.
Kumaon Battalion.
Guide Corps.
4th Sikh Infantry.
1st Punjab Infantry.
2nd Punjab Infantry.
4th Punjab Infantry.
Belooch Battalion.
Pioneers—unarmed.

Captain R. C. Fagan, Artillery.
Lieutenant E. H. Hildebrand, Artillery.
" H. G. Perkins, "
" T. E. Dickens, "

Lieutenant F. S. Tandy, Engineers.
" P. Salkeld, "
" E. Jones, "
Captain F. M. Greensill, H. M.'s 24th Foot, Assistant Field Engineer.

No. 3.

List of Actions fought at or near Delhi, by the Delhi Force from 30th May to 20th September, 1857.

Battle of the Hindan	May	30
„ Ghazeeoodeennugur	„	31
„ Badlee Serai	June	8
Affairs at Hindoo Rao's	„	9
„ „	„	10
„ „	„	11
Attacks on the Flag Staff Tower and Subzee Mundee	„	12
„ Metcalfe Picquet	„	13
Action of Kissen Gunge	„	17
Attacks on British Camp	„	19 & 20.
Action of the Subzee Mundee	„	23
Attack on „	„	27
„ „	„	30
Action of Alipoor	July	4
Attack on British Camp	„	9
Actions of the Subzee Mundee	„	14 & 18.
Affair of Trevelyan Gunge	„	20
Action at Metcalfe House	„	23
„ Kissen Gunge	Aug.	1
„ Koodsea Bagh	„	12
Battle of Najaf Gurh	„	25

THE SIEGE.

No. 1 Battery, made and armed	Sept.	7
No. 2 Breaching Battery, made and armed	„	8, 9 & 10.
No. 3 Breaching Battery, „	„	10 & 11.
No. 4 Mortar Battery „	„	10 & 11.
No. 5 „ „	„	10 & 11.
Breaching and Bombardment	„	12 & 13.
Storming of Delhi	„	14
Capture of Magazine	„	16
„ of the Palace	„	19
City finally evacuated by the enemy	„	20

Assistant Surgeon S. Moore, 6th Dragoon Guards.

Lieutenant-Colonel R. A. Yule, 9th Lancers.

Lieutenant W. W. Pogson and W. R. Webb, H. M.'s 8th, The King's Regiment.

Lieutenant W. H. Mountsteven, H. M.'s 8th, The King's Regiment.

Lieutenant J. H. Bradshaw, H. M.'s 52nd Light Infantry.

Captain F. Andrews and Ensign W. H. Napier, H. M.'s 60th Royal Rifles.

No. 4.

Return of Casualties in the Delhi Field Force, from the 30th May to the 28th September, 1857.

Corps.	Effective Strength of all Ranks on 11th September, 1857.	Killed.				Wounded.				Missing.		Total Officers and Men.
		Officers		N. C. Officers and Soldiers.		Officers.		N. C. Officers and Soldiers.		N. C. Officers and Soldiers.		
		Europeans.	Natives.	Europeans.	Natives.	Europeans.	Natives.	Europeans.	Natives.	Europeans.	Natives.	
Staff ..	..	4	..	..	..	9	..	..	..	..	..	13
Artillery ..	1350	4	1	43	26	23	1	216	49	..	2	365
Engineers ..	722	3	2	4	34	19	1	6	60	..	9	138
6th Dragoon Guards ..	123	1	..	18	..	2	..	9	..	..	..	30
9th Lancers..	391	1	..	26	..	2	1	64	..	..	..	93
4th Irregular Cavalry ..	78	..	..	..	..	..	..	..	3	..	..	3
1st Punjab Cavalry ..	147	..	..	..	1	1	..	..	5	..	..	7
2nd ditto ..	114	..	..	..	..	..	..	..	3	..	..	3
5th ditto ..	107	..	..	..	..	..	1	..	3	..	..	4
Hodson's Horse ..	462	..	..	..	..	1	5	..	5	..	..	11
H. M.'s 8th Foot ..	322	3	..	41	..	7	..	129	..	..	..	180
Ditto 52nd Light Infy.	302	1	..	18	..	4	..	73	..	5	..	101
Do. 60th Rifles	390	4	..	109	..	10	..	266	..	..	..	389
Do. 61st Foot	402	2	..	30	..	7	..	112	..	5	..	156
Do. 75th Foot	459	5	..	79	..	14	..	184	..	3	..	285
1st Bengal Fusiliers ..	427	3	..	95	..	11	..	210	..	..	..	319
2nd ditto ..	370	4	..	79	..	6	..	156	..	..	..	245
Sirmoor Battalion ..	1212	1	..	..	85	6	8	..	219	..	64	383
Kumaon ditto	312	1	..	..	20	2	3	..	38	..	5	64
Guide Corps	585	2	5	..	65	6	10	..	215	..	..	303
Carried ford.,	7,275	39	8	542	231	130	29	1,425	595	13	16	3,028

Lieutenant M. A. Humphrys, 28th Native Infantry, attached to 60th Rifles.

Ensign E. O. L. Phillipps, 11th Native Infantry, attached to 60th Rifles.

Lieutenant T. Gabbett and Ensign S. B. Elkington, H. M.'s 61st Regiment.

Captain E. W. J. Knox, H. M.'s 75th Regiment.

Lieutenant S. J. R. S. Fitzgerald, A. Harrison, and E. V. Briscoe, H. M.'s 75th Regiment.

No. 5.

Return of Casualties in the Delhi Field Force, from the 30th May to the 28th September, 1857.

Corps.	Effective Strength of all Ranks on 11th September, 1857.	KILLED.				WOUNDED.				MISSING.		Total Officers and Men.
		Officers.		N. C. Officers and Soldiers		Officers.		N. C. Officers and Soldiers.		N. C. Officers and Soldiers.		
		Europeans.	Natives.	Europeans.	Natives	Europeans.	Natives.	Europeans.	Natives.	Europeans.	Natives.	
Brought forward, ..	7,275	39	8	542	231	130	29	1,425	595	13	16	3,028
4th Sikh Infy.	414	1	2	..	43	3	7	..	106	..	..	162
1st Punjab do.	664	3	3	..	17	5	5	..	141	..	..	228
2nd Ditto, ..	650	1	1	..	41	2	4	..	103	..	..	152
4th Ditto, ..	541	1	..	..	9	..	2	..	59	..	..	71
	322	1	..	..	7	..	1	..	48	..	1	58
	..	..	..	1	24	..	1	..	128	..	..	155
Grand Total,	9,866	46	14	543	426	140	49	1,426	1,180	13	17	3,854

ABSTRACT.

	Officers.		N. C. Officers and Soldiers.	
	British.	Native.	British.	Native.
Killed	46	14	543	426
Wounded	140	49	1,426	1,180
Missing	..	..	13	17
Total	186	63	1,982	1,623

Lieutenant W. Crosier, H. M.'s 75th Regiment.

Major G. O. Jacob, 1st Regiment Fusiliers.

Captain G. G. McBarnett, 55th Native Infantry, attached to 1st Fusiliers.

Lieutenant E. Speke, 65th Native Infantry, attached to 1st Bengal Fusiliers.

Lieutenant S. H. Jackson.

2nd Lieutenant D. F. Sherriff, 2nd Bengal Fusiliers.

Lieutenant C. F. Gambier, 38th Native Infantry, attached to 2nd Bengal Fusiliers.

No. 6.

Inscription No. 1. *in the Persian Character.*

دهلي کي جنگي فوج کي انگريزي اور هندوستاني افسر اور سپاهي جو ۳۰ مئي اور ۲۰ ستمبر سنه ۱۸۵۷ع کے درميان لڑائي مين مارے گئے اور يا زخمي يا بيمار هوکر مرگئے اُنکي يادگاري کيواسطے اُنکے ساتهيون نے جنکو اُنکي موت کا رنج هے اور سرکار نے جسکي خدمت مين وه اسطرح کام آئي يهه يادگاري بنوايا *

Ensign O. C. Walter, 45th N. I., attached to 2nd Bengal Fusiliers.
„ E. C. Wheatley, 54th N. I., attached to Sirmoor Battalion.
Lieut. J. H. Brown, 33rd N. I., attached to Kumaon Battalion.
„ J. Yorke, 3rd N. I., attached to 4th Sikh Infantry.
Capt. W. G. Law, 10th N. I., attached to 1st Punjab Infantry.
Lieut. E. J. Travers, 2nd I. N., Command 1st Punjab Infantry.

No. 7.

Inscription No. 1. *in the Nagrí Character.*

देहली की जंगी फ़ौज के अंगरेजी और हिनदुस्तानी अफ़सर और सिपाही जो ३० मई और २० सितंम्बर सन् १८५७ ईसवी के दरमियान लड़ाई में मारे गये और या जख़्मी या बीमार होकर मरगये उनकी यादगारी के वास्ते उनके साथीयोंने जिनको उनकी मौत का रंज है और सरकार ने जिसकी ख़िदमत में वोह इस तरह काम आये यह यादगार बनवाया ॥

Lieut. W. H. Lumsden, Adjutant, 1st Punjab Infantry.
Ensign J. S. Davidson, 26th N. I., attached to 2nd Punjab Infantry.
Lieut. R. P. Homfray, 4th Punjab Infantry.
„ Q. Battye, Commandant of Cavalry Guide Corps.
„ A. W. Murray, 42nd N. I., attached to Guide Corps.
„ C. B. Bannerman, Belooch Battalion.

Specification.

Rubble Masonry.—The hearting or body of the work to be of the best description of rubble in lime mortar masonry—due care being taken that the work is efficiently bonded, that the stones are laid on their natural beds, that a sufficient number of through bond stones should occur in every course, and that the interstices be properly filled with mortar.

The mortar to be the same as that used by the local P. W. Department Officers at Delhi consisting of charcoal burnt kunkur lime and soorkee or *budjrí* in such proportions as are found to yield the best mortar.

The work to be carried up in regular courses, and where connections with cut stone occur, to be closely fitted and properly joined with regard to efficient bond.

Plain Ashlar.—The surfaces in the building upon which no string courses, mouldings, tracery, &c., lie, are here called plain ashlar. The lining of the well of the staircase as well as the steps, newel, &c., to be of this description of masonry.

The material used to be red sandstone, the faces of the stones to be very neatly chiselled, straight and out of winding; the beds, tops and tails of the stones to be sufficiently neatly and squarely dressed to lie closely and give fine joints. No defective or discolored stones to be used, and the work should in all respects be the best of its kind. A fine description of mortar being used in its construction. Dowels and joggles to be introduced where needed.

Moulded Ashlar.—All chamfers, tracery, string-courses, mouldings, cornices, raised or sunk work, &c., to be accurately and neatly cut to templates. To be of the same stone as that specified for plain ashlar. Joints to be very fine and correctly wrought to fit close together.

Carved Ashlar.—Poppy heads over gablets, finials of buttresses, bosses, crockets, and all foliated work, come under this denomination. Great care to be taken in carving the different ornaments shown in the design, neatly and correctly and as true as possible to the proper types of the style of architecture in the building.

ABSTRACTS.

Estimate for completing basement of Delhi Memorial Monument.

		Rs.	Rs.
c. ft. 17,342	Rubble in lime mortar masonry, with ashlar quoins, at Rs. 12 per 100, ...	2,081	
s. ft. 6,050	2" thick ashlar flagging, set in mortar, on terrace of basement, at Rs. 15 per 100, ...	908	2,989
	Contingencies, at Rs. 5 per cent, ...		149
	Total Rupees, ..		3,138

Estimate for superstructure of Delhi Memorial Monument.

c. ft. 8,858	Rubble in lime mortar masonry in hearting of shaft, at Rs. 20 per 100, ...	1,772	
5,076	Plain ashlar masonry on face and lining of staircase well, at Rs. 1-2 per cubic foot, ...	5,711	
2,176	Moulded ashlar in water tables to buttresses, cornices, pinnacles, &c., &c., at Rs. 3-8 per cubic foot, ...	7,616	
113½	Carved ashlar, in poppy heads, bosses, crockets, &c., at Rs. 8-8 per cubic foot, ...	965	
No. 1	Marble cross, 8 feet high and 7 feet wide, at Rs. 750, ..	750	
s. ft. 267	Marble tablets, including inscriptions, &c., at Rs. 16 per supl. foot, ...	4,272	21,086
	Contingencies, at Rs. 5 per cent., ...		1,054
	Total Rupees, ..		22,140

Estimate for completing the Delhi Memorial Monument.

Abstract No. 1.

Completion of Basement, ...	3,138	

Abstract No. 2.

Superstructure, ...	22,140	
	25,278	
Grand Total of Estimate, ...		25,278

E. J. M.

No. CLX.

BORATE OF LIME GLAZE FOR TILES.

In connection with a subject which deserves more attention from the Indian Public Works Department, than has yet been paid to it,—the "Glazing of Pottery,"—the following extract from "O'Shaughnessy's Bengal Dispensatory" appears well worthy of being transferred to the pages of the "Professional Papers of Indian Engineering."

In the report which Doctor O'Shaughnessy rendered to the Medical Board, dated 1840, he shows that, the principal difficulty in glazing lay in the rate of contraction in the cooling of the glaze differing so much from that of the clays employed—the glaze peeling off or cracking.

This was the case particularly with the soda clay of Bengal, or *saji mitti*.

New Glaze—The Borate of Lime.

"The results of several trials proved the superiority of the borate of lime.

"I find that it is most easily applied to our new biscuit by mixing the powdered borate into a thin cream with weak solution of the common bazar gum. This mixture is applied with a brush, and the ware is then exposed to the sun, or kiln-dried.

"To fuze this glaze requires a somewhat higher temperature than that needed for the preparation of the biscuit. The glaze being, when properly prepared, transparent and colourless, it leaves the vessel of its natural tint, and as lustrous as the best English ware.

"The lime solution is prepared by dissolving shell lime in bazar vinegar till a neutral liquid is obtained, and boiling this down to the consistence of a thin syrup.

"In working a pottery, the impure pyro-ligneous acid would be employed and prepared on the spot.

"The solution of borax is made by dissolving one pound of *sohaga* (bazar borax) in 12 quarts of warm rain water, and straining through clear gunny cloth. This solution is to be added to the lime solution in portions of a pint at a time, so long as any precipitate occurs.

"The milky fluid is next to be thrown on a calico strainer. The solid matter, which is already finely pulverulent, should be washed with cold rain water: again strained through calico: and dried for use.

"The minute quantity of this article required for the glazing of a vessel renders its expense scarcely worth calculation."

The clay used for the biscuit consisted of four parts Colgong *khari*, and one part *sabún mittí*, or fuller's earth. The khari was obtained from Modiram Hill, Bhaugulpore, Bengal.

Doctor O'Shaughnessy gives no analysis of the clays.

There appears no reason why the Government of Bengal should not move in the matter, and make use of the Cement Experiment establishment and apparatus, to conduct experiments on a cheap mode of glazing bricks, tiles, &c., &c. If these experiments prove to be equally successful with those on "Cement," there will be a new material gained for roofing, to the exclusion of the present abominable system of concrete terraced roofs.

C.

RANCHEE,
28th April, 1875.

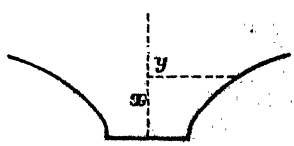
No. CLXI.

FORM OF CHANNEL OF CONSTANT MEAN VELOCITY.

By F. E. Rose, Esq., *Assistant Engineer, D. P. W., Punjab.*

the heavy rains of August 1872, the city of Jullunder was inundated to a great extent, and as the recurrence of a similar flood is a contingency which may be looked forward to, owing to the physical features of the country, and several other reasons which it is not necessary to detail here, a Project—comprising a complete system of drainage and defence works was drawn up—one of the component parts of the project being a drain, which under varying depths, should have a constant mean velocity. And, although the mathematical investigation of the cross-section made it apparent that obligatory practical conditions would preclude anything like a close approximation to a form of channel framed on this principle, yet, inasmuch as the result arrived at is peculiar, exhibiting a singular contour, I am induced to note down the development of the problem, in the hope that it may interest the readers of the "Roorkee Professional Papers."

The problem to be solved is the following:



"To calculate such a contour to the cross-section of a channel, that for all depths (x) of water running in it with a given declivity (p), the mean velocity (v) of the current shall be constant, and equal to a given quantity assigned."

[The origin of the curve to be calculated will be the centre of the channel bottom, the depths (x) will be measured along a vertical line, through

this for abscissæ, and the corresponding half widths at surface (y) will be the ordinates].

Taking the following as the co-efficient for discharge in open channels,

$$V = n\sqrt{p\frac{s}{c}}$$

in which the co-efficient is not specified, and substituting for s and c, the following general expressions for *area* and *perimeter*,

$$s = 2\int_0^x y\,dx \qquad c = 2\int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\,dx$$

we get

$$v = n\sqrt{p}\sqrt{\frac{\int_0^x y\,dx}{\int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\,dx}}$$

or

$$v^2 \int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\,dx = n^2 p \int_0^x y\,dx.$$

Differentiating, we have

$$v^2 \sqrt{1 + \left(\frac{dy}{dx}\right)^2} = n^2 p y\,; \text{ or putting } \frac{n^2 p}{v^2} = n_1$$

$$\frac{dy}{dx} = \sqrt{n_1^2 y^2 - 1}\,; \text{ or } dx = \frac{dy}{\sqrt{n_1^2 y^2 - 1}}$$

[*Note.* y cannot be less than $\frac{1}{n_1}$, *i. e.*, than $\frac{v^2}{n^2 p}$, otherwise the above expression for dx becomes imaginary].

Integrating, we have

$$x = \int_{\frac{v^2}{n^2 p}}^{y} \frac{dy}{\sqrt{n_1^2 y^2 - 1}} = \frac{1}{n_1} \text{Hyp. log} \frac{y + \sqrt{y^2 - \frac{1}{n_1^2}}}{\frac{v^2}{n^2 p}}$$

Converting hyperbolic logarithms into ordinary ones, and giving n_1 its value

$$x = \frac{2{\cdot}30258 \times v^2}{n^2 p} \log \frac{y + \sqrt{y^2 - \frac{v^4}{n^4 p^2}}}{\frac{v^2}{n^2 p}}$$

or putting $\quad \alpha = \frac{n^2 p}{2{\cdot}30258 \times v^2}\,; \quad \beta = \frac{v^2}{n^2 p}$

$$x = \frac{1}{\alpha} \log \frac{y + \sqrt{y^2 - \beta^2}}{\beta}$$

Whence

$$y + \sqrt{y^2 - \beta^2} = \beta \log^{-1} ax.$$

or

$$y = \frac{\beta}{2}\left(\frac{1}{\log^{-1} ax} + \log^{-1} ax\right) \ldots\ldots\ldots\ldots\ldots\ldots \text{(A)},$$

which is the equation required.

QUADRATURE.

We obtained above $dx = \dfrac{dy}{\sqrt{n_1^2 y^2 - 1}}$

which is $dx = \dfrac{dy}{\sqrt{\frac{1}{\beta^2} y^2 - 1}}$

whence area

$$= \int_\beta^y y dx = \int_\beta^y \frac{y dy}{\sqrt{\frac{1}{\beta^2} y^2 - 1}} = \beta \sqrt{y^2 - \beta^2}$$

Or substituting for y from equation (A), we have

$$S = 2\beta^2 \sqrt{\frac{1}{4}\left(\frac{1}{\log^{-1} ax} + \log^{-1} ax\right)^2 - 1}, \ldots\ldots\ldots\ldots\ldots \text{(B)}.$$

RECTIFICATION.

We have

$$l = \int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\, dx$$

But

$$\left(\frac{dy}{dx}\right)^2 = \frac{y^2}{\beta^2} - 1; \text{ and } dx = \frac{dy}{\sqrt{\frac{y^2}{\beta^2} - 1}}$$

$$\therefore l = \int_\beta^y \sqrt{1 + \frac{y^2}{\beta^2} - 1}, \frac{dy}{\sqrt{\frac{y^2}{\beta^2} - 1}} = \int_\beta^y \frac{y dy}{\sqrt{y^2 - \beta^2}}$$

$$= \sqrt{y^2 - \beta^2} = \beta \sqrt{\frac{1}{4}\left(\frac{1}{\log^{-1} ax} - \log^{-1} ax\right)^2 - 1}$$

If in Equation (A) we make $x = 0$, we get $y = \beta$. Hence the perimeter will consist of a horizontal straight portion, 2β, and two curved sides each equal to l, and we shall have finally

$$c = 2\beta\left\{1 + \sqrt{\frac{1}{4}\left(\frac{1}{\log^{-1} ax} - \log^{-1} ax\right)^2 - 1}\right\} \ldots\ldots \text{(C)}.$$

[It may be thought that on account of this straight portion not having

been introduced into the data, the results are vitiated. It will be seen, however, that it is a constant under our hypothesis, and that being simply additive, it would vanish on the first differentiation.

Recapitulation of Results.

We have first the equation to the cross section of the channel, referred to the bed and vertical centre line as co-ordinates.

$$y = \frac{\beta}{2}\left(\frac{1}{\log^{-1} dx} + \log^{-1} dx \right)$$

Secondly, to calculate the area for a given depth x

$$s = 2\beta^2\phi$$

Thirdly, the corresponding perimeter

$$c = 2\beta\ (1 + \phi)$$

And, consequently, the hydraulic mean depth

$$\frac{s}{c} = \beta \frac{\phi}{1 + \phi}$$

in all of which

$$\beta = \frac{r^2}{n^2 p} \qquad a = \frac{\cdot 4343}{\beta}$$

n the co-efficient of discharge, say 96 0

$$\phi = \sqrt{\frac{1}{4}\left(\frac{1}{\log^{-1} ax} + \log^{-1} ax \right)^2 - 1}$$

x = height of surface above bed.

y = corresponding surface half width.

[*Note.*—$\text{Log}^{-1}\ ax$ is the primitive whose logarithm is ax].

Example.

Given a Canal whose maximum discharge at a certain point is to be 924 cubic feet per second, and mean velocity under *all* disharges 3·5 feet per second, the slope being projected at ·0004.

Assuming $n = 96$; we have $\beta = 3{\cdot}33$; $a = {\cdot}13$.

By the conditions area of cross section for full discharge

$$= \frac{924}{3{\cdot}5} = 264.$$

Consequently, we must have

$$s = 2\beta^2\phi = 264; \text{ or}$$

$$22\phi = 264$$
$$\phi = 12.$$

For rough approximation we may take

$$\phi = \tfrac{1}{2} \log^{-1} ax.$$

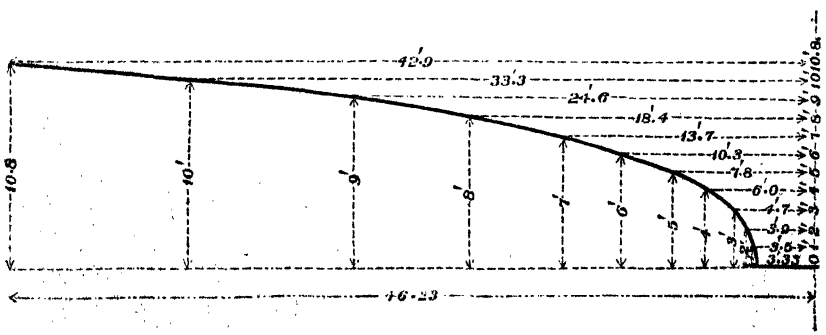
$\therefore$ we have $\log^{-1} ax = 24$, or $ax = \log 24$,

whence $x = \frac{1{\cdot}380211}{{\cdot}13} = 10{\cdot}6$, or say 10·8 for the full depth of channel at centre.

Now, from the principal equation, giving x successive values 0, 1, 2, &c., up to 10·8, work out the corresponding values of y as per Table annexed.

From these quantities the curve has been plotted in the diagram.

x	·13 x	Log^{-1} ·13 x	$\frac{1}{\text{Log}^{-1} \cdot 13\, x}$	Sum × 1·665 $= y$.
0	..	..	$y = \beta =$	3·33
1	·13	1·349	·742	3·50
2	·26	1·820	·550	3·90
3	·39	2·455	·407	4·70
4	·52	3·312	·302	6·00
5	·65	4·467	·224	7·80
6	·78	6·026	·166	10·30
7	·91	8·139	·123	13·70
8	1·04	10·970	·091	18·40
9	1·17	14·800	·068	24·60
10	1·30	19·960	·050	33·3
10·8	..	..	..	42·9



General Observations.

A glance at the diagram will show that we work on a wrong principle, viz., making our side slopes too steep.

In fact, that contrary to the universal practice of making the half section of a channel *concave* it ought to be *convex*, with a kind of independent channel in the centre to confine extremely small supplies, which might thus be utilized instead of being allowed to waste by evaporation.

Nature herself would seem to point to something akin to this in streams of variable supply. Let any one observe Punjab rivers at their lowest, and mark in any straight reach the great banks of silt on each side sloping towards the thin central stream, at the edge of which there is a sudden drop into the low water channel.

The great advantage of such a channel would be its thorough permanency and equable action.

On the other hand its drawbacks would be,—to state one or two—

(i). Increased expense of construction.

(ii). Increased waste by absorption.

(iii). Difficulty in cases of embankment.

Although no one would apply this precise form of channel to practice, yet it will be readily admitted that the nearer we *can* approach it the better.

F. E. R.

No. CLXII.

MEMORANDUM ON THE REMOVAL OF OBSTRUCTIONS IN THE MAHANUDDY & BHAGIRUTHEE RIVERS.

[*Vide* Plates XXXIII. to XXXVI.]

By Lieut. A. O. Green, R.E., *Secy. to the Torpedo Committee.*

At the commencement of the Famine year of 1874, it was foreseen that it would be necessary to provide communications between the bases of supply, *i. e.*, between the Loop Line of the East Indian Railway and the Ganges at various points, and the famine threatened districts, for the transport of grain; and the resources of the Public Works Department of Bengal were strained to the utmost to carry out the numerous proposed works.

Roads were commenced, where not previously existing, from the various grain depôts established on the railway and the banks of the Ganges, and carried into the heart of the famine stricken districts; existing roads were improved; and last, but not least, a temporary railway was under the superintendence of Major Stanton, R.E., rapidly laid down from the Ganges to Durbhunga, a distance of 48 miles.

It was, however, deemed that all these means of communication would prove barely sufficient to carry the enormous traffic that it was expected would pass over them, and it was, therefore, considered advisable to open up the inland water communications as much as possible, so as to relieve the roads and railways wherever practicable. This was particularly the case in the Rajshahye Division of Bengal, where large depôts had been established on the line (as at Rajmahal) and on the Ganges (as at Rampore Bauleah and Godagáree); and great use was made of the Maha- river, which joins the Ganges at Godagáree, in transporting the

grain in country boats from thence to various branch depôts on its banks for subsequent distribution inland.

No sooner did the Mahanuddy become the scene of a largely increased amount of traffic, than it was found that there were great practical difficulties in the way of getting the largest class of country boats, carrying from 600 to 800 maunds apiece, up the river even as far as Maldah. This was not so much owing to the shallowness of the water during the dry season of the year, as to the numerous obstructions which occurred in the channel, and which would prove peculiarly dangerous to navigation during the rains. As it was urgently required to work the river beyond Maldah at least as far as Chooramun, a distance of about 49 miles, it was necessary to get rid of these obstructions, which consisted of wrecks, sunken trees, old masonry foundations, &c., as well as to remove the various shoals in the river. This latter portion of the work and the deepening of the channel at various points, was entirely carried out by the Public Works Department, under the superintendence of the Executive Engineer of the Nuddea Rivers Division.

In the early part of March, Mr. Wickes, the Executive Engineer of the Nuddea Rivers Division, applied through the Superintending Engineer of the North East Circle, to the Secretary to the Government of Bengal in the Public Works Department, for the services of a Sergeant of Sappers and Miners to blow up these wrecks, &c., as he had no means at his own disposal of doing so himself. Application having been made to the Government of India in the Military Department, the matter was referred to Col. Hyde, R.E., the President of the Torpedo Committee at Calcutta, and on his recommendation it was decided that the Secretary of the Torpedo Committee, accompanied by a Sergeant of Engineers, and a small party of Sappers, should proceed to Maldah, where they were to be joined by a detachment of one Havildar and 12 Sappers from Roorkee, to carry out the work of the removal of these obstructions.

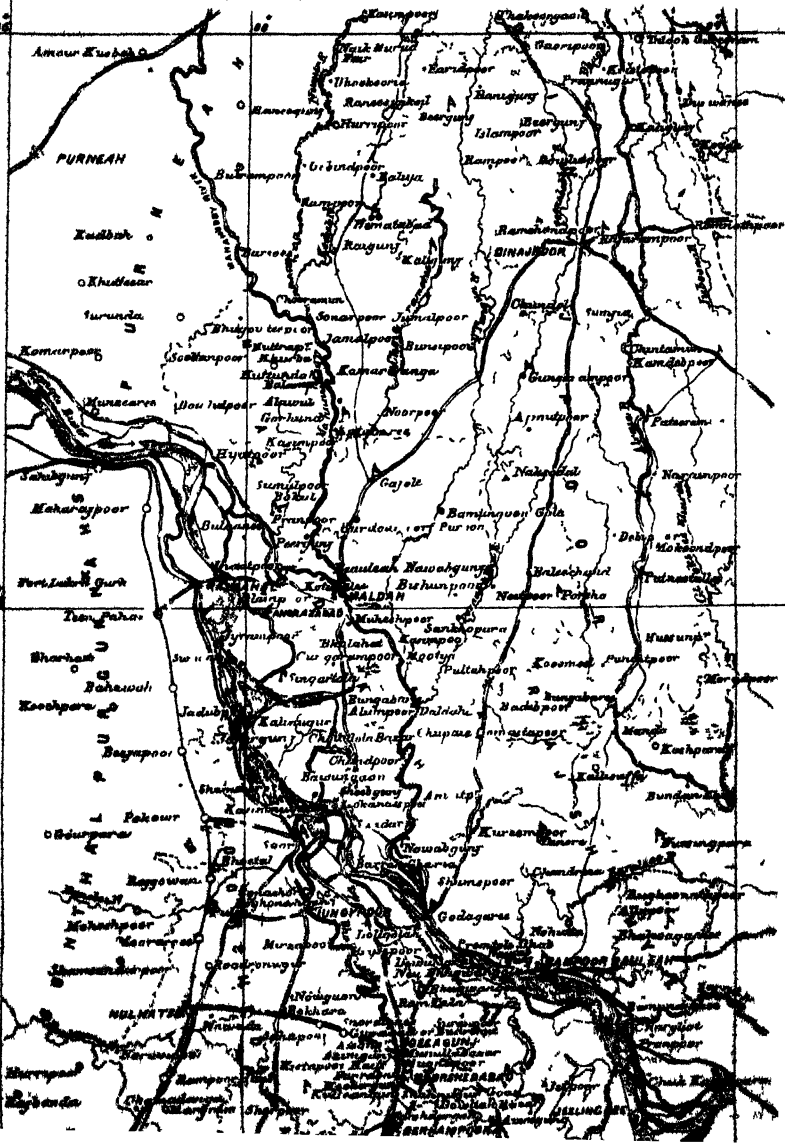
It was not, however, until the 31st March, that my services as Secretary to the Torpedo Committee, were finally placed temporarily at the disposal of the Public Works Department of Bengal; and a further delay of a week occurred, owing to the difficulty experienced in obtaining precise information of the nature of the obstacles to be overcome, before I could start for Maldah, taking with me one European Sergeant, two Sepoys, and two native Divers, together with a large quantity of stores.

MAP

SHOWING THE COURSE OF THE

RIVERS MAHANUDDY AND BHAGIRUTHEE.

N.B.—*The portions of river cleared of obstructions are colored red*


PURNEAH
Amour Kuttah
Khuddesar
Kumurpoor
Maharajpoor
Sharbait
Bahawulee
Koohpara
Bagnapoor
Pakaur
Rajmahal
Nawabgunge
Buhumpoor
Berhampoor
Kurseonpoor
Jungypoor
Godagaree
Nuddea
Kishnagur
Bhagirathee
Hooghly
Calcutta
Diamond Harbour
Saugor Island
Balasore
Pipley
Kedgeree
Hidgelee
Tumlook
Midnapoor
Jellasore
Bundwan
Kasimbazar
Moorshedabad
Jungypoor
Sooty
Dhulian
Nuddea
Kishnagur
Santipoor
Fultah
Baughnapara
Bansberia
Chandernagore
Hooghly
Howrah
Calcutta
Diamond Harbour
Saugor Island
Kedgeree
Hidgelee
Tumlook
Midnapoor
Jellasore
Balasore
Pipley
Bundwan
Kasimbazar
Moorshedabad
Jungypoor
Sooty
Dhulian
Nuddea
Kishnagur
Santipoor
Fultah
Baughnapara
Bansberia
Chandernagore
Hooghly
Howrah
Calcutta
Diamond Harbour
Saugor Island
Balasore
Pipley
Kedgeree
Hidgelee
Tumlook
Midnapoor
Jellasore

The calculation of these stores was roughly estimated at what it was thought would be necessary for the removal of the obstructions, the number of which was known between Maldah and Chooramun only, which was the section of the river that most urgently required clearing; and they consisted of the following:—

Gunpowder, ...	2000	lbs.
Gun-cotton, ...	300	„
Fuzes, "Electric, Abel, sub-marine,"	84	
Ditto platinum wire, ...	100	
Old oil cans to contain charges, ...	30	

Also 400 yards of insulated wire (7 Straud Hooper's Core), and various small stores.

The above party left Calcutta on the 8th April, and reached Maldah on the 10th, where it was joined by the Sappers from Roorkee. Work was commenced on the following day by an attempt to remove the wreck of a large country boat which lay on the top of a tree in midstream, opposite to Angrezi bazaar, the civil station of Maldah.

Soundings were taken over and around this tree, which was found to be about 3 feet 6 inches in diameter at its base, and the gunpowder not having arrived, three 5 lb. charges of gun-cotton, each of which would be equivalent to about 25 lbs. of powder, were made up, and it was thought that under the 15 foot head of water these would have been sufficient to smash the tree in half.

The gun-cotton was in the form of compressed discs, $2\frac{1}{2}$ inches in diameter, and 2 inches thick, each disc weighing about 5 ounces. These discs fitted into a tin cylinder which was filled with them to within about 4 inches of the top of the cylinder. A fuze, with firing wires attached, having been securely rammed into the hole in the centre of the top disc, the empty space above was filled up with a layer of sawdust, and then a layer of damp earth, well rammed round the fuze.

The whole was then coated over with white lead paint, and over this was tied a covering of common waxed cloth, the fuze wires being brought up through a hole cut in the centre which was afterwards waterproofed with the mixture given below, which has been found to answer the purpose admirably.

Tallow, ...	5	per cent.
Rosin, ...	15	„
Guttapercha, ...	20	„
Pitch, ...	60	„

Plate XXXIV., *Fig.* 1, gives a section of one of these charges made up. The first charge was placed at the root of the tree in about 15 feet of water. It was fired by means of a dynamo-electric machine, a description of which is given at the end of this Article (*vide* Appendix and *Plate* XXXVI.) Its effect, as far as could be ascertained was poor, probably not having been properly placed by the diver. The next charge failed from the case giving way, and was spoilt for the time being, until the gun-cotton could be re-dried. This wet charge would have fired, had only the disc into which the detonating fuze was rammed been kept dry by a covering of waxed cloth. The third charge, which was placed under the trunk of the tree, was more effective, as it lifted the boat and tree somewhat out of the water.

It was, however, determined to await the arrival of the gunpowder, which fortunately turned up the next morning, having been delayed in transit by rail. As soon as possible two charges of 70 to 80 lbs. of powder, which it was considered was about the proper amount required, were placed under the boat, being lashed on to the snag by the divers.

These charges consisted simply of the common oil tins of commerce, carefully cleaned out and painted over with red lead paint; the bung hole was closed by a wooden plug, bored out to admit the insulated wire to the fuze, earth being made by a small piece of bare copper wire from the other end of the fuze, twisted round the insulated wire to a short distance outside the wooden plug. *Fig.* 2 will fully explain the above arrangement of the plug, which was then placed in the bung hole, and coated over with waterproofing mixture.

Charges made up thus were very handy to use or to keep in store, and when the Magnetic Exploder was used with Abel's high-tension fuzes, only one insulated wire was required from the charge to one pole of the battery, the circuit being completed by a copper earth plate held in the water by a short piece of insulated wire from the other pole.

The effect of the above two charges was to completely demolish the boat, but it required another charge of 50 lbs. to remove the tree underneath, which it apparently did altogether, but, subsequently, a portion of it being found still remaining, a fourth charge of 20 lbs. of powder had to be used to get rid of it entirely.

Fig. 3 gives a section of this snag, and the position of the charges.

In the evening we went up the river to the junction of the Kalandria and Mahanuddy, where there was a sand bank (*Fig.* 4) formed by a boat

REMOVAL OF OBSTRUCTIONS IN THE MAHANUDDY AND BHAGIRUTHEE RIVERS.

Fig 2.

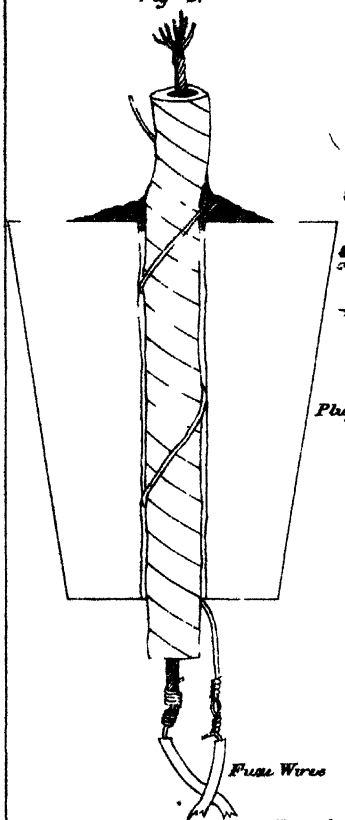


Fig. 4.



Fig. 1

a Hooper's 7 Strand Insulated Wire
b—No 22 Gauge, Copper Wire
c—Water Proofing Mixture
d—Waxed Cloth Covering
e—White Lead Paint
f—Damp Earth
g—Saw Dust
h—Gun-cotton Discs
j Tin Case

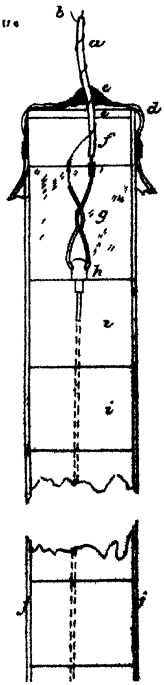
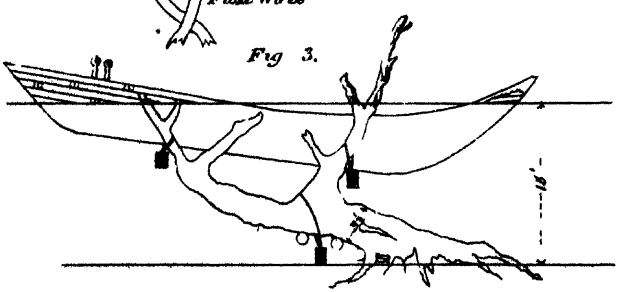


Fig 3.



which had broken in half, and then sunk. This sand bank was a great obstacle to the navigation, especially during the dry season, and I had little hope of removing it, as the sand had accumulated almost entirely over the boat, leaving little but sand to operate upon.

However, a charge of 80 lbs., (it being considered that one large charge was preferable to two or three small ones in getting rid of the sand,) placed close to the part of the boat that was visible, made a considerable crater, and I was able to place a second charge of 80 lbs. in a much more favorable position, as nearly all the boat was removed except portions of the bow and stern, which required two separate charges of 50 lbs. each, before they disappeared. In half an hour the whole of the sand bank had been washed away by the stream, and there was from 3 to 4 feet of water over the spot, where before the sand was high and dry out of the water. The removal of this obstruction was dangerous, owing to the nearness of the boat to the surface, the consequent small resistance offered to the projection of its pieces through the air, and the largeness of the charges used. Had, however, small charges been used, it is more than probable that the small craters made by them would have become too quickly filled up again to have been of any good in facilitating the placing in position of subsequent ones.

The following day a large mango tree, about 4 feet 6 inches in diameter was destroyed near Bauleah Nawabgunge, by two 50 lb. charges, which broke it up into three pieces, easily removable ashore.

Considerable delay was now experienced from the difficulty of procuring boats, and it was not till the 17th April that I was able to make a fair start from Maldah. Intending originally to proceed up the river to Chooramun, I was forced to alter my plans, as I learnt that much time would be lost in looking for the snags, which had not been marked out, and that the upper part of the river was not so bad as the section towards Godagáree, which was now urgently required to be cleared first. Indents for more powder and cases were accordingly sent down to Calcutta to be complied with as soon as possible, and two country boats of about 400 maunds each, one for stores and the other for the detachment, having been hired at Maldah, we started off down the river to Bholáhát. Here opposite to the village, a large trunk of a tree, about 3 feet in diameter was removed with two 50 lb. charges; but the depth of water over it was so small that a large portion of the trunk was thrown a considerable dis-

tance on shore, and struck the corner of a pucka building, but fortunately without doing any damage. The next day, a large tree which had formed a sand bank here, was very successfully removed by a charge of 50 lbs. placed among the roots, it being considered that a smaller charge than 50 lbs. would not have effected the purpose. Opposite to Kásimpore, a boat was removed with a charge of 50 lbs. placed in the centre up-stream, which entirely demolished it, the pieces being all dragged ashore. At Mootyá a large cotton tree, the wood of which is extremely tough, was found with many large branches projecting out of the water. A charge of 70 lbs. tied under the tree at the springing of the branches effectually broke it up, and the pieces were all hauled to land. Three miles further down the river, an attempt was made to destroy another large cotton tree, with a similar charge, but it only broke it into three pieces, and two more charges of 50 lbs. each were necessary to clear it away effectually. This tree was, if anything slightly larger than the last, *i. e.*, from 3 to 4 feet in diameter, and there was less water over it.

On the 19th April, we came across a collection of three or four trees, with their branches interlaced, lying on a sand bank near Alumpore Dáldah; these were sufficiently broken up by a 70 lb. charge to make them easy of removal by coolie labor, and being high and dry on the sand, and therefore dangerous only during the rains, they were left, as it was dangerous blowing them to pieces by gunpowder. Opposite to the village, another awkward snag in the shape of a large tree sticking up in 30 feet of water was destroyed by trying a 70 lb. charge at its base. 50 lbs. of powder under this head of water, or even a smaller amount, might have been sufficient, but as the work had to be done quickly, not much account was taken of a few pounds of powder more or less, provided the object was attained. This snag was very dangerous from its position at a bend in the river. At Gomashtapore we found a large tree, branches and all, in 25 feet of water, lying in the channel under the left bank. The current here was considerable, and we had some difficulty in placing the charges. One charge of 70 lbs. broke the tree in half, 50 lbs. at the springing of the branches broke them up, and another charge of 50 lbs. got rid of the roots, and the whole was hauled ashore. Below Gomashtapore a large mango tree was demolished with 60 lbs. of powder. A short distance further on we came across a bad bamboo snag. These bamboo snags, which were merely the roots of the bamboos with perhaps a dozen or so whole ones

left, were the worst form of snag with which we had to deal, and gave us the most trouble.

Plate XXXV., *Fig.* 1, gives an idea of what these snags are like.

It was found impossible to place a charge underneath this one, so an opening was prized open between the bamboos, and a charge of 70 lbs. rammed down pretty well into the middle. This cleared the whole of it away and opened the channel.

Another clump was got rid of in a similar manner a little further on. We had to knock off work at 1 P. M. on this day, as the heat was very great in the sun, the thermometer standing at 103° inside the Gomashtapore *thanah*, where the famine officer lived. In the evening, we went on down to Chandpore, and pitched our camp for the first time since leaving Maldah.

Here close to the camp, and at a re-entering angle of the river in a place peculiarly dangerous to navigation during the rains, was an enormous banyan tree (*Ficus Indica*), the main trunk of which, to judge from the branches must have been at least from 12 to 15 feet in diameter. An approximate measurement was made with a pole, but any such measurement can only have been a very rough one.

The trunk was lying in deep water, but the branches, more like an accumulation of large trees, were lying stretched out for a considerable distance over the bank, covering an area of more than 80 square feet. A charge of 200 lbs. of powder was made up in an india rubber bag, and placed by the divers in about 28 feet of water, well under the trunk of the tree. The effect of this was to split the trunk up into several pieces, each of which subsequently required separate removal. A 70 lb. charge was next fired under two of the largest pieces in 18 feet of water, and this broke them up completely. Having now run out of all our cases for powder, three charges of gun-cotton, similar to the first, were made up as before, and fired separately, each placed under a good thick branch about 8 feet in girth. The effect of all three was prodigious; seemingly greater than that of the 70 lbs. of gunpowder. As there were no more cases left, and time was precious, some common earthenware ghurrahs were obtained from the village as a makeshift. These held about 20 lbs. of powder, the fuze being placed in the centre in a disc of gun-cotton, and the neck was closed up with damp earth, white lead paint, &c., just in the same way as the gun-cotton charges had been. A rope

for lashing them to the obstacle was securely fastened round the neck, and the fuze wires were tied under this lashing, leaving a small loop towards the fuze free, so as to avoid any chance of a strain being brought on the fuze in lowering the charge. *Fig.* 2, shows the arrangement of this charge. The first one tried had but little effect when placed under a branch of the tree in deep water, and it was accordingly determined to wait for cases from Calcutta; but after waiting five days without their appearing, three more of these charges were tried, and this time with very excellent results.

In fact, they were so satisfactory that the same evening four more were made up and fired. The first under a mango tree a little further down the river. This broke it in half, throwing one part high and dry on shore, and the other into deep water. The other three were fired under the remaining branches of the banyan tree with very good effect, cutting them away.

It is more than probable that the good results obtained with all these ghurrah charges were entirely due to the gun-cotton disc inside, causing the gunpowder itself to detonate, so that the thinness of the envelope was of little moment in determining the force of the explosion.

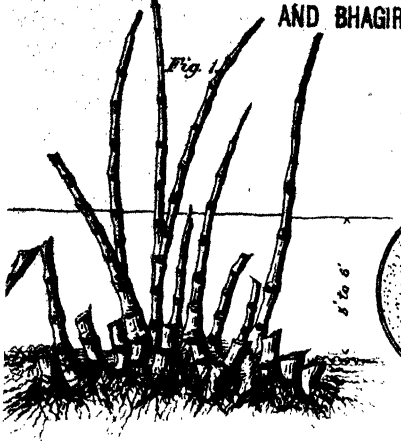
The tin cases having arrived, the rest of the powder was made up into five charges of 48 lbs. and three ghurrah charges of 20 lbs. each. About four miles farther down the river, there was an old peepul tree lying in mid-channel, with several of the branches above water. Two tins, one placed under the springing of the branches and the other under the roots, blew away the lower branches on which the tree was resting, and it sank slightly in the water. A ghurrah was next fired under the trunk with most splendid results, the tree disappearing entirely except one branch, which required another small charge to remove it.

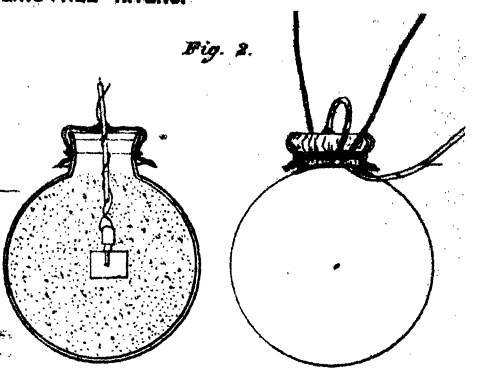
The trunk of this tree was nearly 8 feet in diameter but of soft stringy wood.

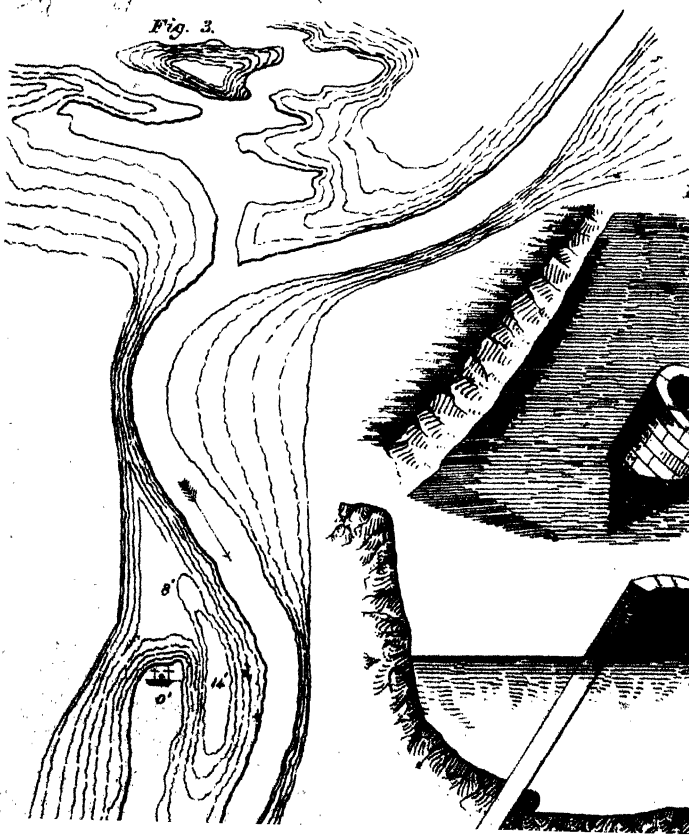
On our return to camp a small charge of 2 lbs. of gun-cotton was made up in a section of bamboo, and used against the banyan tree with very good effect, and a ghurrah charge demolished the last branch but one. The next day 1½ lbs. of gun-cotton in a piece of bamboo finished the last of this enormous tree over which we had spent so much time, but chiefly owing to the want of material. A further delay of 10 days now took place, and it was not till the 10th May, that the second supply of

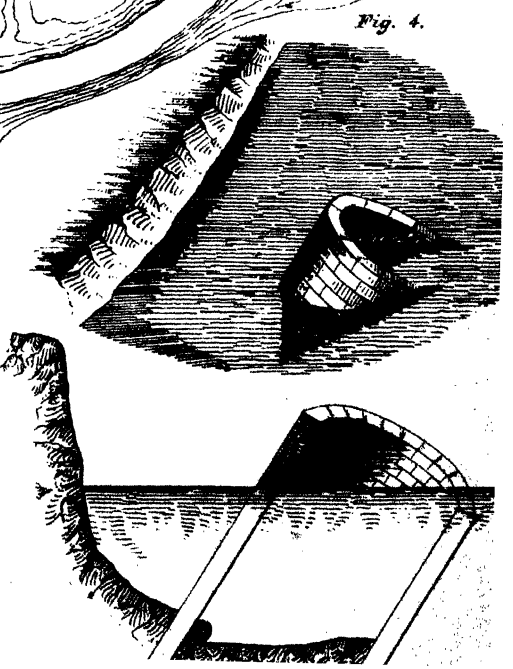
PLATE

REMOVAL OF OBSTRUCTIONS IN THE MAHANUDDY AND BHAGIRUTHEE RIVERS.









powder arrived in camp. During this time the weather was very hot, and although encamped under a grove of mango trees, the thermometer in my tent went up to 126° in the middle of the day very frequently. I note this fact to show how safe it is to carry gun-cotton about during the hot weather.

Our boxes of gun-cotton were kept dry in the open air, with just merely a tarpaulin thrown over them.

Several more trees and collections of trees, &c., were cleared away farther down the river, and on the 12th of May the foundations of an old factory, which had slipped into the stream, were removed by introducing two charges of 1½ lbs. of gun-cotton in the ends of two bamboos, well into the crevices of the masonry under the water. The brickwork was all reduced to powder, and would entirely disappear as soon as the river rose after the commencement of the rains. Above Nawabgunge several snags were removed, and just below three boats.

One of these had formed a sand bank in mid-channel, and was somewhat difficult to remove. Here we lost the only ghurrah charge that we had the misfortune to lose during the whole time.

The current was strong, and the charge not being properly tied down under the side of the boat, was broken and the powder lost.

It was impossible to peg it down as the sand was so shifting. This boat was subsequently cleared away with one charge of 50 lbs. in a tin case. The last obstacle in the river, a large country boat embedded in a sand-bank just above Godagáree, was removed on the 14th May, and the party returned to Maldah, which was reached on the 17th following. On the 23rd May, after being again delayed a week for powder, a fresh start was made up the river to Chooramun.

The first obstacle to be removed was met with about 12 miles above Maldah.

It consisted of a row of old piles, about 15 inches square, stretching across the river beneath the surface of the water. The natives said that there had formerly been a bridge here; but it is more probable that they were the piles of a bund made for irrigation purposes. Six of the most dangerous of these were removed from the dry season channel with ghurrah charges by tying them on at the foot of the piles. From Maldah up to Aláwal the river is excellent. It runs through a clay bed, and is more like an artificial channel, the banks are so straight and the slopes so regular.

Its breadth throughout this part is from 80 to 100 yards. Just above Aláwal, it suddenly widens out into a broad, shallow, sandy reach, with only one very shallow navigation channel, and this was blocked up by snags.

Here more than 80 boats loaded with rice had collected together, and were waiting for the rains to enable them to go on up to Chooramun. There was one boat on the top of a snag, but as they hoped to get off in a few days, it was not removed.

One snag in this reach, the trunk of a large tree lying in very shallow water had to be blown to pieces. The operation was successful, but dangerous, some of the pieces being projected at least 150 yards away. Having removed a sunken boat which had caused a great deal of inconvenience, the boats were, enabled to pass up the river. Hitherto nothing but 'high tension' fuzes had been used in conjunction with the magnetic exploder; but having run out of these, we were obliged to have recourse to platinum wire fuzes, fired by a Wollaston Sand Battery, a description of which is given in the Appendix.

This form of fuze is not so convenient as the high tension fuze for work with in a boat, as the liquid in the battery is liable to be spilt, and rapidly dries up in a hot sun or wind. It requires also in fresh water a return wire from the fuze to the other pole of the battery to ensure certain ignition: but this was very simply done by twisting a No. 22, B. W. G. bare copper wire from the fuze round the insulated Hooper's Core, and leading them at the battery to the two opposite poles. Four more obstructions, two boats and two trees, were next removed without much trouble; but the difficulty experienced in obtaining food for the party made me determine to push on to Chooramun with as little delay as possible.

Up as far as this, the water in places was very shallow, and there was considerable delay on this account in getting the boats up to Chooramun, which was reached on the 27th May. Here a very bad obstacle, in the shape of a very large tree with numerous branches, was removed, but it took one 50 lbs. and nine 20 lbs. charges to get rid of it effectually, each branch taking a separate charge.

A country boat which had sunk close by, was removed with one 50 lb. charge. Eleven more obstructions, chiefly large mango trees, were removed in the next two days from the river just below Chooramun, and on the 31st May the party started on its way back to Maldah.

On the way down, two or three more snags were removed and four more piles of the bund. Maldah was reached on the 1st June, and arrangements were made for sending the party down the Mahanuddy into the Ganges, and from thence it was to cross over into the Bhagiruthee, at the mouth of which a large steamer, the "River Bird," had been wrecked during the mutiny, and was gradually closing up the river channel.

It was proposed to remove this steamer on our way down to Moorshedabad, and whilst the boats started down the river on the 4th June, I left for Calcutta for more powder, &c.

On the 9th June, I reached Berhampore, and having obtained an old *budgerow* from the Executive Engineer, started up the river towards the Ganges, taking in powder and stores at the Azimgunge railway station on the way up. We found the steamer "River Bird" so completely silted up and buried under sand and water that it was impossible to do anything towards her removal. *Plate* XXXV., *Fig.* 3, gives an idea of her position.

Between Jungypore and Gysepore two tree snags, and an old well, which had tumbled bodily into the water, were removed. The latter, the position of which is shown in *Fig.* 4, was destroyed completely by a charge of 4 lbs. of gun-cotton, which was used as an experimental charge. Five more snags were cleared away below Gysepore, two of them being removed by hauling on them with ropes, and without the aid of powder.

Opposite to Baboo Dhunput Singh's temple, near Azimgunge, there was the trunk of a very large peepul tree sunk in deep water. It was so large that it was thought necessary to place a 100 lb. charge underneath it, which broke it up completely, but two small charges of 20 lbs. were required to remove the pieces.

A large quantity of fine fish were killed or stunned by the concussion, and fell an easy prey to the boatmen and sepoys.

On the 14th June a well similar to the last was destroyed near Furrabad. The brickwork was remarkably good, and about 3 feet thick, and mortar was excellent. One charge of 4 lbs. of gun-cotton broke it up into large pieces, and it took another similar charge, and two charges of 20 lbs. of powder to destroy it completely. Two trees were removed on the same day at Mookergunge, with two of the ghurrah charges, which had been used throughout for small charges with unvarying success.

At a place called Farrashdangah, there was a very bad obstruction in

the river caused by the remains of an old bathing ghat and bridge, having been cut out from the bank by the water getting underneath the masonry. Both were projecting about 3 feet above the water, and in the rains they formed the centre of a very nasty and dangerous whirlpool in which many boats had, according to the Executive Engineer of the Nuddea Rivers Division, been lost. There was an immense mass of masonry, but no means of getting a charge placed underneath it, so a charge of 100 lbs. of powder was placed close alongside it in about 15 feet of water. This shunted the mass bodily over and underneath the water. Two 50 lb. charges were next placed underneath the mass, and these shattered it all up, except one piece, which was got rid of with a fourth charge of 20 lbs. placed well underneath it. The Executive Engineer wishing that the wing-wall of the bridge, which was on dry land during the dry season, might be removed as well, a small hole was made with difficulty, (as we had no proper tools, nor were there any in the Public Works Godown at Moorshedabád,) at the foot of the visible portion of the brickwork, and a charge of 2 lbs. of gun-cotton was introduced into this, and fired with only a tolerable effect, the brickwork being cracked for a distance of 3 or 4 feet from the centre of the charge. A hole was next dug down about 5 feet at one side of the wing-wall, and a charge of 4 lbs. of gun-cotton well tamped, was fired. The tamping was blown out, and the wall foundations cracked a good deal. The excavation was now deepened to 6 feet, and a hole made under the brickwork big enough to contain a 100 lb. charge. It was then well tamped up and fired. Its effect was excellent. All the brickwork of the wing-wall was got rid of, and a crater about 30 feet in width at the top blown out in the point of the bank that was required to be removed and which was one of the chief causes of the whirlpool, so that the next rise of the river was sure to carry it all away. The following day an old pucka ghat opposite to Berhampore was entirely broken up with three 20 lb. charges, and an enormous quantity of old bricks thrown into the river.

The last operation was undertaken on the 18th June, and consisted in the blowing up of a very large ghat opposite to the Nawáb of Moorshedabád's palaces. The river during successive rains had cut into and underneath the steps of the ghat, bringing down large masses of it into the river, where they formed most dangerous obstacles to navigation, and a whirlpool being formed here in the angle between the bank and fallen masonry, the current

was deflected across with great force to the opposite side of the river, causing considerable and yearly increasing danger to the grounds in front of the palaces. As much as 2000 to 3000 rupees seems to have been annually spent in preventing the encroachments of the river on the Moorshedabád side, and many attempts had been made to get rid of the prime cause of all this mischief, by blasting, but hitherto without success. Having no jumpers or mining tools with me, and being unable to procure any from the Public Works Department at Berhampore, I was obliged to carry out the work in a very rough way. Deep excavations were made under the three largest masses of masonry at about 25 feet apart, and into these were introduced three 50 lb. and one 20 lb. charges of powder connected up in divided circuit. The charges were all well tamped up and fired. All the masonry was broken up completely so as to be easily removable afterwards by coolie labor, which was all that was required.

On the 19th June the detachment of Sappers was sent back to Roorkee by rail from Azimgunge, after having worked most excellently with me for more than two months, during both very hot and rainy weather, and often under the most trying circumstances, being sometimes for two days together without food, and wading about for the most part of the time up to their waists in water.

The boatmen having all absconded, the Sepoys most willingly took their places, and I never had in consequence the slightest difficulty on that score.

The remainder of the party reached Calcutta by rail on the 20th June, having been absent nearly eleven weeks, during which time over 250 miles of river had been cleared of all obstructions that had previously existed.

The time would have been, however, much shorter had it not been for the delays experienced in obtaining the required stores from Calcutta.

The conclusions to be drawn from the foregoing notes, are, that large trees lying in shallow water require charges of 50 lbs. of gunpowder and upwards for their effectual removal; but that where there is plenty of water, and the trees are not very large, 20 lbs. is sufficient.

For these small charges it has been seen that the common earthenware ghurrah answers admirably, only one failing out of nearly one hundred fired, and I think that under similar circumstances it would be advantageous to use them as they are inexpensive and obtainable in nearly every village.

The charges used might in many cases at first have been no doubt made smaller with advantage, both as regards safety and economy; but as speed was the great object these were not so much thought of.

The safety with which compressed gun-cotton can be carried about in a dry state, and subjected to great variations of temperature was demonstrated in a marked degree. A considerable portion of the gun-cotton taken with the party was subsequently brought back to Calcutta and used in blowing up a wreck at sea, and it does not seemto have at all deteriorated, although it was exposed in simple open, wooden, tin-lined cases in camp throughout the whole of the hot weather, and part of the rains.

For the removal of masonry under water, it is not necessary to place the charge underneath the mass, which is often impossible; a large charge alongside it being generally quite sufficient to break it up pretty effectually where there is a sufficient head of water. Smaller charges can of course be easily used afterwards, whenever required, and for these small charges gun-cotton is very effective, as it can be so easily introduced into holes and crevices in the end of a bamboo, where it would be impossible to get any but the smallest charges of gunpowder.

It will, however, be of little use removing snags from rivers and streams, unless the officers in whose charge they may be, are empowered to prevent their rapid re-formation by removing growing trees from too close a proximity to banks liable to be cut away by floods during the rainy season.

A. O. G.

APPENDIX.

The material and appliances used in the clearing of these two rivers, although not in the possession of every Executive Engineer, or Civil Officer, are cheap, and with the exception of gun-cotton, easily procurable.

The fuzes employed were those known as "Detonators, electric, Abel, submarine," and "Detonators, electric, platinum wire," both of which are specially intended to be used with gun-cotton primers. The first of these is a chemical fuze, and is adapted to the electricity obtained by friction, or to the momentary induced currents, derived from permanent or electro-magnets, or an induction coil. It can also be ignited by the direct Voltaic current; about 60 cells of Daniell's, or 30 cells of Grove's, battery being necessary to overcome the resistance with *certainty*. Although the whole of the fuzes which were sent to Maldah were successfully fired with the dynamo-electric machine, yet subsequent experience with this

kind of fuze shows, that they are in no way to be depended upon, and are certainly not adapted to this country.

Nor are the various other forms of chemical fuze to be much relied upon, unless the priming material has been freshly made up, as it is so very liable to deterioration in a hot or moist climate.

The following fuzes are however fairly good, and may be easily extemporized:—

A small cylinder, *Plate* XXXVI., *Fig.* 1, of hard wood or cork, about $\frac{5}{8}$-inch in diameter and $\frac{3}{8}$-inch thick, is provided with a groove *a*, round its circumference, and two perforations *b*, *b*, about $\frac{1}{4}$-inch apart, of a suitable size to receive two moderately thin pieces of copper wire (about 18 B. W. Gauge being a convenient size). One extremity of both of these wires is sharpened with a file, and then converted into a hook, the head of which is afterwards flattened, as shown in *Fig.* 2.

The straight ends of the wires are then passed through the holes in the cylinder, and the flattened heads are fixed in the wood by driving the pointed extremities into the latter. In this way the broad thin metal surfaces, which form the poles of the fuze, are fixed in a parallel position on the surface of the wood or cork, and should be as close together as possible, without actually touching. This arrangement is shown in *Fig.* 3.

Before, however, the wires are thus placed in position, the surface of the cylinder, upon which the poles are fixed, is brushed over lightly with a feather tip or hair pencil, which has been dipped into a solution of ordinary photographic collodion. When the poles have been fixed into the cylinder thus prepared, the small surface of wood which intervenes between them is coated with graphite, by drawing a pointed black lead pencil across it two or three times. A cap of thin paper is then tied round the cylinder, *a*, *Fig.* 4, so as to enclose the poles of the fuze; this cylinder is filled compactly with fine grain gunpowder and the open end is then choked as shown at *b*, *Fig.* 4.

The protruding wires of the fuze, *c*, *c*, *Fig.* 4, which serve to connect it with the conducting wires, are coated, to within a short distance of their extremities, by moulding ordinary beeswax round them with the fingers, and then tightly wrapping the wax over with thin strips of tape or rag of any kind, which is secured at the end with thread. The entire fuze, except the bare ends of the wires, may be then brushed over with any varnish or lacquer which may be at hand.

This fuze may be fired by means of a voltaic battery of sufficient power, or by Wheatstone's magnetic exploder, the former of which generates a continous current, and the latter a rapid succession of short currents.

It would rarely be fired by means of a frictional or other machine capable of producing a single discharge only, because, in order to produce the necessary heating power, a continous passage of the current through the plumbago bridge, is essential. In using this fuze, it frequently happens that a short interval elapses between the closing of the electrical circuit and ignition, this time being required to produce the necessary amount of heat alluded to.

Another form of fuze is similar in general construction to the above but differs in the composition of the bridge. For plumbago, a mixture of powdered charcoal and rosin is substituted; and this produces a fuze that tests well, and is very certain of ignition. The above fuze is the invention of Captain Fisher, R.N.

The "detonators, electric, platinum wire" fuze used are shown in *Fig.* 5. They are precisely similar in outward form to Abel's chemical fuze, and the only difference is, that the bridge consists of $\frac{3}{10}$-inch of thin platinum wire, weighing 1·6 grs. to the yard, instead of the chemical mixture of graphite and fulminate of mercury in the latter. Platinum wire fuzes possess numerous advantages in their employment in any subaqueous work, and the following may be cited:—

1st.—Great facility in testing the fuze, which offers only a very slight resistance to the passage of a current of electricity, and which resistance is not liable to alteration on account of the metal of which it is composed.

2nd.—Non-liability to deterioration on account of climate.

3rd.—It can be easily improvised, and the materials of which it is composed are simple.

4th.—It does not require the very high insulation in the conducting cable, which is necessary when a fuze, fired by a current of high tension, is used: and it may be fired through a cable in which a comparatively large fault exists.

5th.—There is no danger of an accident during the process of testing, for which purpose more powerful batteries of Daniell's or any other form may consequently be safely used.

The dynamo-electric machine used for firing the high tension fuzes

REMOVAL OF OBSTRUCTIONS IN THE MAHANUDDY AND BHAGIRUTHEE RIVERS.

Fig. 1



Fig. 2



Fig. 3



Fig. 4.



Fig. 5

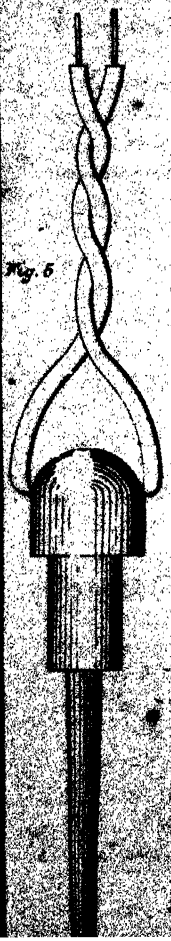


Fig. 6

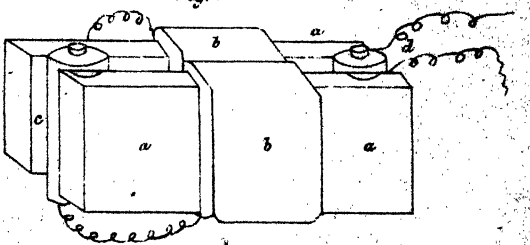


Fig. 7

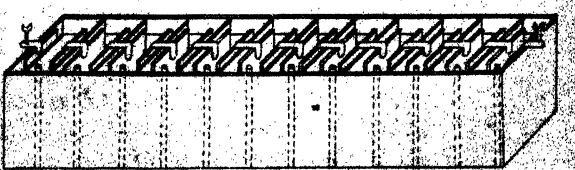


Fig. 8

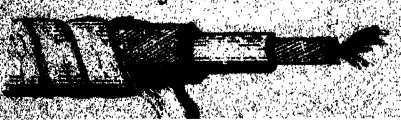


Fig. 9



was made by Mr. Ladd, of Beak Street, London, and is a very compact and useful instrument. *Fig.* 6, gives the general arrangements of the instrument; *aa* are two soft iron bars, round which coils of fine insulated wire *bb*, are wound, in metallic connection through a commutator, with the coil of an armature *c*, revolving between their extremities. When the armature *c* is made to revolve rapidly, the residual magnetism in the soft iron bars *aa* induces a series of currents of electricity in the coils of the armature. The currents thus induced in the coils of *c*, circulate through the coils *bb*, and increase the magnetism, which in its turn re-acts on the coil *c*, and induces a stronger series of currents, and the result is, that the two bars *aa* become very powerful electro-magnets, the poles of which are so arranged, as to be opposed to each other at their extremities. Now, instead of discharging the current thus induced through the working circuit, to fire fuzes, which necessitates beginning again to create a new current, a second armature *d*, revolving between the soft iron bars is introduced, and from this is obtained the working current; the magnetism of the bars is thus always kept up.

The employment of any machine similar to the above, necessitates absolute insulation of the cable.

The firing power used with the platinum wire fuzes was an ordinary "Wollaston's Sand Batttery" of 12 cells. It is shown in *Fig.* 7. The cells are of wood in the form of a trough, with wooden partitions between each cell, and the inside is lacquered with a mixture of shellac and guttapercha. The plates are of the ordinary size, $3\frac{1}{2}'' \times 4\frac{1}{2}''$. They are alternately copper and zinc, connected together in pairs, by copper strips rivetted and soldered to them. The zinc plates are amalgamated with mercury, and the cells filled with fine siliceous sand, moistened with sulphuric acid diluted with water in the proportion of $\frac{1}{15}$.

It acted very well for the purpose required of it, as it was capable of developing a large current when first made up, but it has the disadvantage of being inconstant, and of quickly losing its electro-motive force.

The liquid too, dries up very rapidly by evaporation when used during the hot weather in the open air, and a small quantity of diluted acid should always be kept ready to moisten the sand with, and should be poured down the guttapercha tubes inserted in each cell and extending down to the bottom.

By thus introducing the fresh acid at the bottom of the cell, where the

heavy sulphate of zinc gravitates, a more regular action is obtained. If the sulphate of zinc be allowed to accumulate in the lower part of the cell a cross voltaic current is established, between the upper and lower portions of the plates, which are in solutions of different strengths. The effective current in circulation is thus diminished, and the upper portions of the zinc plates are rapidly dissolved away. The sand is used to prevent the acid from spilling, when the battery is moved about; it tends also to make the action of the battery more regular; but it should not contain carbonates, such as carbonate of lime, or a chemical action takes place with the sulphuric acid which is detrimental to the battery.

The electric cable used, which is very suitable for the purpose, is called "Seven Strand Hooper's Core." It consists of a strand conductor of seven No. 22, B. W. G. copper wires, tinned, the electrical resistance of which is 10 Ohms, nearly, per statute mile. Over the conductor is a thin coating of raw indian rubber, then a thin coating called a separator, of indian rubber mixed with oxide of zinc; over this is a thickness of vulcanized indian rubber, and the outside is protected by a layer of indian rubber felt.

It has high insulation, flexibility, and capability of withstanding dry atmospheric heat. *Figs.* 8 and 9 give an elevation and section of this cable.

The following Table gives a list of the materials required in removing snags, &c., their prices, and the places from whence they can be most readily obtained both at home and in India:—

Alphabetical List of Stores.

Commercial Name.	English Price. £	s.	d.	Where obtainable in England.	Indian Price. Rs.	A.	P.	Where obtainable in India.	Remarks.
Acid, sulphuric, per lb.,	0	0	2	..	0	2	0	Dr. Waldie's Chemical works, Cossipore.	
Beeswax, „	0	1	9½	..	0	15	0	Bazaar.	
Core, Hooper's, 7 Strand, per mile,	65	0	0	Hooper's Cable Company, Mitcham,	852	8	0	Govt. Telegraph Stores, Alipore, Calcutta.	
Copper, sheet, per cwt.,	4	0	0	...	52	0	0	Do.	
Fuzes, electric, submarine, Abel's, per 100,	3	11	6	Mr. Ladd's, Beake Street, London,	43	13	0	Arsenal, Fort William, Calcutta.	Not issuable without special sanction.
„ „ platinum wire,	3	10	10	Do.	43	13	0	Do.	
„ extemporized, per doz.,	0	3	9	Do.	3	0	0	Govt. Telegraph Stores.	
Gunpowder, per barrel of 100 lbs.,	..	..	..	..	20	0	0	Any Arsenal.	
Gun-cotton, per lb.,	0	2	0	Messrs. Prentice and Co., Stowmarket,	1	2	0	Arsenal, Fort William.	Not issuable without special sanction.
Guttapercha, „	..	..	..	Indian Rubber, Guttapercha and Telegraph Works, North Woolwich,	1	6	0	Govt. Telegraph Stores.	
Lead, red, dry, per cwt.,	1	0	0		7	15	0	Messes. Ahmuty & Co., Calcutta.	In most bazaars.
„ white, ground, „	1	5	4		16	1	0	Do.	
Machine, Dynamo-electric,	10	10	0	Mr. Ladd's, Beake Street, London.					
Pitch, per cwt.,	0	8	6	..	0	11	3	Kidderpore Dockyard, Calcutta.	
Rosin, „	0	6	6	..	5	0	0		
Solution, indian rubber, for insulating joints, per lb.,	0	1	3	Messrs. Henly and Co., North Woolwich,	1	8	0	Arsenal, Fort William.	
Tape, indian rubber ½ lb. roll,	0	2	10½	Do.	1	10	0	Do.	
Tubing, ½" indian rubber, per 10 feet,	0	3	9	Do.	2	0	0	Do.	
Tins, linseed oil, empty,	..	..	..	..	1	0	0	Bazaar.	
Wire copper, No. 22 B. W. G., per lb.,	0	2	0	..	1	4	0	Telegraph Stores.	
„ platinum, per oz.,	1	10	0	..	15	0	0	Arsenal, Fort William.	
Zinc, sheet, 15 B. W. G., per cwt.,	1	16	0		20	0	0	Telegraph Stores.	

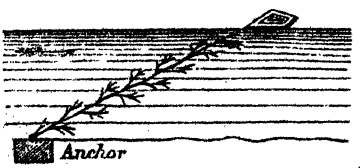
No. CLXIII.

FLOATING SPURS FOR RIVER TRAINING.

Memorandum on the use of Floating Spurs in Training Rivers flowing in alluvial soil. By Lieut.-Col. H. A. Brownlow, R.E., *Supdg. Engineer, Irrigation Department, Punjab.*

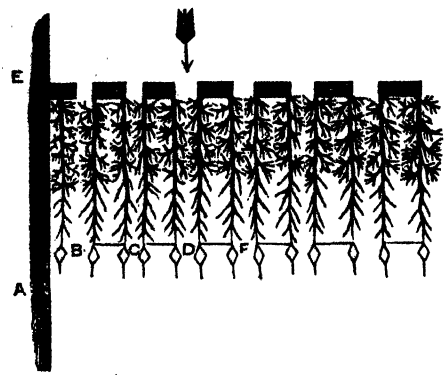
The object of the floating spur is to imitate the action of weeds in flowing water, and by checking its velocity to bring about the deposit of silt in any channel which it is desired to close. The advantages of the system are, that the flow of the water is only checked and not totally obstructed, that all violent action and scour along the face and at the toe of the spur are thereby avoided; that as silt is deposited in the channel the hydraulic mean depth and velocity of the stream are decreased, so that the work helps itself on: that the change effected is gradual, giving the water time to scour itself out a new channel, whilst the old one is being closed; and, finally, that the river is made to do the work of filling up its own channel, which, if merely closed off by a solid embankment, would always remain unfilled and a source of danger.

The construction is very simple. A stout hawser, of a length equal to three or four times the depth of the stream, is strongly fastened to an anchor at one end, and to a buoy at the other, and to it are attached branches and brushwood, or small trees may be lashed to it by their butts.



The anchors may consist of concrete blocks or of crates or strong nets

full of kunkur and brick bats, and should be heavy enough when immersed to resist the drag of the current on the streamer. They can be sunk in line with fair accuracy from a derrick in the bows of a boat, should the water be too deep to admit of their being filled and closed when in place.



The buoys can be omitted if the current be very strong and likely to carry away the streamer. The latter would then lie along the bottom, powerfully checking the bottom velocity and rapidly reducing the depth of the channel by the deposit of silt. Where buoys are used, it might be advantageous to keep each adjacent pair apart from each other by light rigid connecting rods B C, D F, so as to prevent the streamers from getting twisted together.

The streamers should be bushed more heavily at the bottom than at the top in order to prevent under cutting, and be placed closer together at the heel than at the toe of the spur. The portion of bank AE should be protected with especial care, so as to guard against the water cutting round the heel, or into the bank below the spur. Rough pitching of a sloping bank, or hanging trees, head downwards, from the crest of a vertical bank will ensure its protection.

The alignment of the spur can either be perpendicular, or at an inclination, to the axis of the current, for the water passing freely through the spur, no violent set is imparted to the stream and no scour takes place along the up-stream face or at the toe. On the Satlaj, the streamers were successfully used in lines parallel to the bank, and a foreshore may thus be created to a perpendicular bank that is being undermined.

Spurs on the above principle have been tried with success on the works for training the river Satlaj above the State Railway Bridge at Adamwahan near Bahâwalpûr. Much interesting information on the subject is given by Mr. Graham, the Exec. Engineer in charge of Training Works in his Report, which was published in the 16th Quarterly number of the "Professional Papers of Indian Engineering," as Article No. CLII.

H. A. B.

No. CLXIV.

BULL'S SEMI-CONTINUOUS BRICK KILN FOR COAL.

[XXXVII.].

By W. Bull, Esq., *Resident Engineer, Oudh and Rohilkhand Railway.*

This process, hereafter described, combines in itself three methods of obtaining heat, viz., by horizontal firing with either wood or coal, as in a flame kiln; by vertical firing with small coal, as in Hoffmann's kiln; and by distributing a certain portion of fuel amongst the bricks to be burnt, as in a coal clamp.

The kiln is a long chamber, the bed of which is on a slope, the length very much greater than the width, both of which are variable and determined by circumstances, as shown below. The chamber may be dug out of the earth, may be built (of either kucha or burnt bricks set in mud) on sloping ground above the level of the surface, or may be a combination of the two, being partly dug and partly built up. The side walls only of the kiln are permanent, the wall at lower end being built up, and taken down each time the kiln is fired, and the upper end being closed by loose bricks (forming part of the load) plastered over with mud, as explained further on. Whether a brick lining is required for the earthen sides in the kiln, or part of kiln below surface, must be determined on in each case from consideration of the nature of soil, &c. The only additional brickwork required is in forming the flues at lower end, which extend but a short distance longitudinally, the remainder of the kiln being simply a plain sloping floor with perpendicular sides. The accompanying Plans and Sections, show the general form of kiln, and method of setting the bricks.

CK KILN FOR COAL.

ch.

hrough Wall LM.

respectively.

Grou

Level.

a a

b b

ng course

ak on edge pocket course
t brick spanning those below
" single

ugh lower Flues NO.

Grou

Level.

Part Plan of Kiln.

B

The floor of the kiln being on an inclination, such a strong draught is caused, that the whole of the fuel used, burns in a most effective manner; a greater 'duty' is consequently realized from it, than can possibly be the case in the slow burning clamps so commonly used. The waste heat from the fuel in burning and from the bricks burnt, is all gently forced forward and utilised to the utmost extent. This being done without any chimney flues and chambers (except in the brick themselves), or dampers, gives a simple and economical form of kiln. We thus have combined in this system—economy in first cost of kiln, economy in fuel and quick delivery. It is a surprising fact, but one which can be vouched for by many who have seen this kiln working, that notwithstanding the very short space of time allowed to elapse between firing and unloading, the bricks are perfectly sound and ring like metal. Owing to this quick delivery, a kiln to hold two and-a-half lakhs can easily be burnt twice in a month. A single kiln should, therefore, turn out, taking 80 per cent. (two lakhs per kiln) as serviceable out-turn, 30 lakhs pucka bricks in a season. A kiln of this size should cost Rs. 250 as a maximum, if half excavated and half built as shown in *Plate*. Two such kilns, with a longitudinal wall separating them, worked together, will be found most convenient, as the fuel pipes and covering can be moved from one to the other as required. Constant work is also found for the men firing, and also a continuous supply of bricks.

The width of kilns would depend on the thickness of the bricks, and should, for reasons which are hereafter shown, be equal to the thickness (on edge) of 70 or 118 bricks. The length will be according to circumstances. On sloping ground, the kiln may be entirely excavated from the ground at a very low cost. The longer a kiln is, the greater the economy, as a long kiln only takes the same fuel to start it as a short one.

The kiln is worked as follows:—The flues at the lower end are first set as far as the half chamber. Then the bottom flues between the half chamber and the 3rd chamber, including the pocket course. This is shown in the 4th part of the plan. Between the half chamber and the 1st and 2nd chambers, the bricks, as shown in plan *bb*, are then set with a pocket course over all. This pocket course spans the half chamber, (although the first two did not,) and runs on over the flues quite up to the end wall. This longer flue, with the first pocket course, should now be set between the 1st and 2nd chambers. Then a second layer on the wall between the 1st and 2nd, omitted, quite up to the end, as shown in section. The men

then go back and recommence between the 4th and 5th chambers, and bring that layer up in steps, and so on, until the section takes the form shown in the sketch. Loading is carried on in this manner up to the end, which is carried up vertically. Outside, a single brick casing is to be set for one-third the height, precisely the same as the bricks loaded, and above that set close. The whole is to be covered by a brick flat, over which, after setting the feed pipes (by simply placing them over the right pair of spanning bricks, and putting a dab of clay round them), is to be spread a few inches of earth or ashes, care being taken to prevent any going through the bricks by smearing a little soft mud over the interstices.

In the pocket courses over the flues, three complete rows of pockets at the lower end should be filled with coal in every course, and every alternate row after that. The object of this is to ensure the bricks over the flues being burnt, as the draught is so great that they get very little heat from the firing. All the pockets between the chambers in the lower course should be well filled with coal, and after the 8th chamber, all the pockets in the 2nd course. This leaves less to be done by firing from the top, which is more troublesome than simply distributing the fuel amongst the bricks.

In the pocket courses, every alternate pair of bricks spans the chamber, beginning with a different pair in the 2nd course, so that below each pair of spanning bricks, there is a space through which the coal drops. This will be best seen in the cross section. The result of this arrangement is, that the coal fed through the pipes is divided and distributed over a considerable width. With the exception of a few at the top, where it is not required, every pair of spanning bricks intercept some coal every time it is fed, in exact proportion to the quantity consumed in the intervals between the feeds. The coal not thus absorbed after being ignited by contact with the already burning fuel on the spanning bricks, falls with the nicest regularity along the whole chamber across the kiln, and being acted on by a constant draught through the lower flues, burns completely away, leaving nothing but pure ash. The perfect diffusion of heat over the entire section of the kiln by this arrangement is manifest. Another advantage resulting from this method of setting is, that the higher the bricks are loaded, the smaller the number of feed holes required, owing, of course, to the great spread of the coal. I would not, however, recommend the bricks to be loaded more than three higher than shown in section. In

place of *seven* feed holes, *five* only would be required with a proportionately larger feed. The section shown admits of 70 bricks; with the same height loaded, the feed holes will be from centre to centre thus, 3 + 8 + 12 + 12 + 12 + 12 + 8 + 3 = 70 bricks. With three bricks more, they will similarly be thus 3 + 16 + 16 + 16 + 16 + 3 = 70 bricks.

The top pocket course in the latter case should be the same, but the bottom one will be the same as the second course shown in the Section.

1*st*. *Firing the flues below.*—When loading has been completed as far as 25 rows of feed holes, firing can be commenced, taking it for granted that loading will proceed at the rate of six lines of feed holes daily. If this is not certain, a greater length must be completed before starting, or the steam and smoke will interfere with the men loading. The fires should be started from the wall flues, working towards the middle and fired steadily, keeping the fuel as much as possible int he mouths of the flues, unless there is a very strong wind flowing into the mouths of the flues; they can be kept open from first to last of the firing below if with wood and coal after the heat is over well established. The object in both cases being to get the heat in the bottom flues up until the bricks are at as great a heat as possible without vitrifying, and keep it up until the first row of feed holes on the top is ready to close, after which it would be slackened down for 24 hours, and then entirely stopped.

2*nd*. *Firing the kiln from above.*—This can be commenced when the bricks up to the 3rd or 4th line of feed holes are red hot from bottom to top, which will be in 20 to 36 hours, but less in the hot weather. The plan to be acted on being, that in no case should a line of feed holes be started until the coal ignites freely on being dropped. The first line having being commenced, a second one can be started after three hours. By adopting this rule, the starting and closing the feed holes will proceed regularly, as it has been found that six rows firing at the same time are sufficient, and that the first row will be sufficiently fired in about 20 hours. No exact time can of course be given for closing a line of feed holes, the settlement of the bricks being the safest guide, but as the heat is carried forward so very fast, the settlement in front of the 2nd row of feed holes should be observed, if the earth on the top is spread level. This will easily be seen, and if not, it is a good plan to have a brick set level with a work on the side of the casing, so that by stretching a line across, the settlement

can be exactly observed. An inch will generally be sufficient, but more or less may be required according to circumstances.

3rd. Arranging for the draught.—This must be done according to circumstances, bearing in mind that a free draught should always be allowed. It is done by covering or uncovering as the case may be the feed holes at the top. By allowing the smoke and waste products of combustion to escape at a temperature in which the hand cannot be borne, a sufficient draught will generally be ensured. If the wind is blowing against the kiln, or there is no wind at all, six lines of holes in advance of the last one being fed, should be kept covered, but more can be so if the wind is blowing into the mouths of the flues below. Except under special circumstances, the rule I have found to answer has been to cover each line of feed holes by a brick or one of the covers on each pipe as the steam is driven off until firing is commenced at the top, and after that to keep six lines covered in front of the last one firing. To draw the heat to the sides, it may be advisable to keep all the side feed holes open, except those firing and one beyond, especially with a new kiln. From the action of a wind, should the heat be driven so as to burn one part more than another, which can be seen from the settlement, it may be necessary to close a single feed hole or more in a line, before the whole row is ready. Starting the feeding of a new row should, however, be in a complete line, so as to bring the firing back to the regular number as soon as possible. Three days after firing below has been stopped, the loose brick on the lower flues wall should be taken down, and as the lower end of the kiln cools, the bricks should be unloaded, so that a sufficient draught may be admitted. Unloading can be commenced a week after the kiln has been fired.

For six courses of bricks, as shown in the Section, intercepting the coal fed from the top, 1¼ lbs. at each feed will be sufficient, and should be given every quarter hour regularly, having started each line with six measures to each feed hole. Care should be taken that the earth is spread evenly over the top of the kiln, one inch below the top of the feed holes, a little sand or ashes spread round the pipe will then ensure the cover settling down so as to keep in the heat, which is a most important point. The covers should only be removed for as short a time as possible whilst feeding.

The pipes should be six inches long by four inches interval diameter, and the covers six inches interval diameter and two and-a-half inches deep, with vertical sides, and a small hole in the middle for lifting them. Both,

if well burn burnt, will do several times. If not, they give trouble by constantly breaking. Cast-iron covers if available are best, but the pipes can be of earthenware. If the lower flues are fired with wood, the ash flues will hardly require raking out at all; if with coal, they should be raked out once every 12 hours, and once every three hours the ashes and clinkers found should be raked out from the fires.

The upper end of the kiln should be protected from a wind blowing down it, or the draught will be hindered: this can easily be done by tatties or mats. Lines of feed holes are closed finally by removing the covers, and putting on each pipe a dab of clay, which should fit tightly down on the pipe, so as to keep in the heat fully.

It may be as well to mention, that the object of keeping up the firing in the lower flues after the bricks immediately in front have been burnt, and several feed holes above closed, is two-fold. *First*, to prevent the immediate cooling down of the flue bricks from a white heat, which must take place if the fires are dropped at once. *Secondly*, to prevent the heat in the bottom of the kiln (along the floor) being too rapidly carried forward which, if allowed, would result in some of the coal on the floor remaining, unburnt. By continuing the firing below *cautiously* until six or eight lines of feed holes above are closed, a perfect combustion of the coal which falls on the floor is ensured, and a much better result obtained. Under no circumstances should the bricks in the lower flues be allowed to get vitrified. This process has been patented, the Agents for the same being Messrs. Burn and Co., Calcutta.

W. B.

No. CLXV.

MOUNTAIN RAILWAY FOR THE NILGIRI HILLS.

Compiled (by the Editor) from the Reports by MAJOR A. DE C. SCOTT, R.E. *Under Secy. to Govt., P. W. D., Madras—and* CAPT. J. L. L. MORANT, R.E., *District Engineer, Nilgiri Hills—annotated by* LIEUT.-COL. J. H. WHITE, R.E., *Depy. Consulting Engineer for Railways to Govt. Bombay.*

[THE question of "Mountain Railways" is one of considerable importance to India, in connection with the numerous English Settlements, Military Stations, Tea Plantations, Timber Forests, &c., on the Himalayan Ranges, which form, for many hundreds of miles, the Northern boundary of the country,—with the Military defence of the Passes leading to and from our North-Western and North-Eastern Frontiers,—and with other Hill tracts (such as the Nilgiris) in different parts of our Indian Possessions. The extension of such systems as those of Messrs. Fell and Riggenbach is engaging the attention of Engineers in most countries of Europe and America; and in regard to these, the reader is referred to a recent number (for March 1875) of the *Annales des Ponts et Chaussées*, in which brief descriptions are given of all the principal *Chemins de fer de Montagne* at present in use or under construction. The following extracts from the official correspondence, which has lately passed on the subject of a "Mountain Railway" to the Nilgiris, will probably prove interesting to the readers of the "Professional Papers of Indian Engineering," and may induce Engineers interested in the matter, to take up the question of introducing such

Railways in other (mountainous) tracts of the country. As the construction of the line up the Nilgiris is still *sub judice*, it is not proposed to discuss the project in all its bearings, or to dwell on the action, past or proposed, of Government in the matter; nor would it fall within the scope of the present paper to reproduce *in extenso* the very complete and able reports, from which this Article is compiled. In regard to the report submitted to the Madras Government by Major A. de C. Scott, R.E.—which embodies full statistics, and a careful analysis of the information collected "in regard to the existing traffic to and from the Nilgiri Hills *viâ* the Coonoor ghat, the charges with which it is at present burdened, the prospective increase of such traffic from the extension of colonization and cultivation, and under the influence of facilitated communication by rail, and generally the prospects of the success of a railway in a financial point of view;"—the greater portion which treats of traffic, competition of other lines of communication, and other questions of local interest and importance, has been omitted as foreign to the scope of this publication, while the extracts selected for the purposes of this article are such as bear more exclusively on the *Engineering* aspect of the question, or which are necessary for a proper understanding of the subject. In Major Scott's Report, the discussion is directed to four heads of enquiry:—

1*st*.—The existing amount of traffic on the ghat road, and which would be immediately subserved by a railway.

2*nd*.—The prospective traffic which would be attracted by a railway from other lines of road, or which would be created by increased facility of communication, and by the natural extension of colonization.

3*rd*.—The probable cost of various systems of railway as applied to the Coonoor ghat.

4*th*.—The relative economy of carriage up the ghat by railway, and by the existing means of transit as bearing on the possibility of continued competition between the two systems.

Of these, the first two heads, having a local and special interest only, are here omitted, and quotations are made from the last two 'heads,' preceded by a description of the Nilgiri District.

The interesting Report by Captain J. L. L. Morant, R.E., deals very fully with the Engineering details of the scheme: it was originally

accompanied by several Appendices, giving much information on the line over Mont Cenis, that ascending the Rigi, and other European works; but the addition of these would have rendered this Article too long, and the reader will probably be able to refer to the books and periodicals to which references are made in these Reports, as furnishing information on the European Mountain Railways.

The proofs of this paper were submitted to Lieut.-Colonel J. H. White R.E., who has had many years of experience in Railways in Bombay, and being at Ootacamund interested himself in the subject of these Reports; and the value of the Article is enhanced by several notes from his pen.—ED.]

Extracts from Report by MAJOR A. DE C. SCOTT, R.E., *Under-Secy. to Govt., P. W. Dept., Madras, to the Chief Engineer and Secy. to Govt. P. W. Dept.—Dated 24th April*, 1874.

General description of the Nilgiri District.—The Nilgiri District includes the elevated tract of country which is bounded by Mysore territory and the Coimbatore District on the north, by the Coimbatore District and Malabar on the east and south, and by the Malabar District and the Koondah mountains on the west. Its area is about 749 square miles, and it is on all sides, except towards the Koondahs,* well defined by the hill slopes which fall more or less precipitously to the country below. Although the general characteristic in reference to the surrounding country is that of an elevated plateau, the surface is diversified by hills which assume in some parts the character of distinct ranges. The difference of level between the different parts of the country which are included within the district is considerable. Coonoor, Kotagherry, Pykarra, Ootacamund, and the low country near Mettapolliem, are approximately 5,911, 6,571, 6,766, 7,361 and 942 feet above the sea level, while the higher peaks which rise above the general level, such as Dodabetta, vary in height from 7,000 to 8,640 above the sea. The surface in fact consists of a succession of rounded hills, valleys and water-courses, the recesses and sheltered parts being generally wooded; the slopes towards the low

* The Koondah mountains are an extension of the Nilgiri ranges (at generally a somewhat higher level) but possessing similar features.

country densely so. Water is abundant, the climate temperate, slight frost at night is not uncommon in the cold seasons, but the temperature in the shade never rises above 77°. A considerable area of land has been taken up by European planters for the cultivation of coffee, tea, and cinchona. Australian timber has also been planted with success, and the cultivation of cereals and vegetables as well as the raising of stock is carried on to a considerable extent by the indigenous and imported population. There are said to be about 300,000 acres more or less fit for cultivation, of which only 60,000 acres have been taken up. The population by the latest returns amounted to nearly 50,000 persons, and consisted of—

Europeans and Eurasians, ...	2,135
Military, ...	500
Indigenous and imported natives of India, ...	46,687
Aboriginal tribes, ...	635
Total ..	49,957

The export of coffee in 1874, including the produce of the Ouchterlony Valley on the north-west slopes, amounted to not less than 4,000 tons, the value of which, at the current prices, was about £440,000, and the value of the exports and imports together did not probably fall short of three-fourths of a million sterling. The plateau is pierced by several large streams, and the valleys or ravines by which they reach the low country accommodate roads or pathways more or less easy of ascent. The principal lines of communication are the through trunk road between Mettapolliem and Goodaloor, passing through Kullar, Coonoor, Wellington (the Military Cantonment), and Ootacamund; the road between Ootacamund and Tippoocadoo down the Segoor ghat to the Mysore District; the new Kotagherry ghat between Kotagherry and Mettapolliem; and, lastly, the Sispara ghat leading to Malabar. The first-mentioned road is by far the most important, the last is only used by coolies. There are also a number of local roads giving access to different estates and intersecting the settlements at Coonoor and Ootacamund. The district is much resorted to by Europeans from the Madras Presidency during the hot season, *i. e.*, from April till November, and visitors from more distant parts of the country, Bombay and even Calcutta, are tolerably numerous. Coonoor and Ootacamund are now Settlements of considerable importance, and contain a number of permanent European residents, and

the district is rapidly increasing in importance from the extension of colonization.

Probable Cost of a Ghat Railway.—Captain Morant, the District Engineer of the Nilgiris, has compiled a useful abstract of the information which exists regarding the cost and working of railways on steep gradients, and he has carefully and clearly summed up the arguments in favor of the adoption of the system he advocates and now worked on the Rigi mountain in Switzerland, and which consists in a central rack rail acting as a fulcrum for the motive power to work on, with two outer rails as guides to the wheels of the locomotive and vehicles.

The four classes into which ghat railways have been divided in the papers referred to, possess in certain respects, as is there shown, distinctive features and distinctive advantages or disadvantages. The systems treated of are :—

1*st.*—Railways of ordinary gauge working on inclines seldom exceeding 1 in 25, and generally limited to 1 in 40 or 1 in 45.

2*nd.*—Narrow gauge lines on gradients seldom exceeding 1 in 50.

3*rd.*—Steep inclines worked by stationary engines.

4*th.*—Central-rail railways with locomotives.

Disadvantage of Ordinary Railways.—It has been established by experience that the first class are very expensive to construct and to maintain on a ghat. They must be worked by heavy engines in order to secure the necessary adhesion which will enable sufficient power to be utilized to overcome the resistance of gravity with a fair load. The roadway and rails must be proportionately strong, and at the same time the length of line is considerable compared with the gain in altitude, and the average gradient sufficiently flat to be much at variance with the ordinary natural slopes of a mountain chain, and therefore difficult to trace and expensive to work out. Narrow gauge lines are reported to have been constructed in Norway at a very low cost, and to have taken considerable loads up inclines of 1 in 54, but the data available in this country, which is derived from current experience in the construction of the Carnatic Railway, and which therefore cannot be impugned, does not support these statements of low cost, and the amount of adhesion which must have been required to drag the loads asserted to have been moved is so great, that it could not be calculated on in the case of the Coonoor ghat, where for many months it rains daily.

Inasmuch as the cost of a line is a function of the width of the roadway, the permanent way, the bridges, embankments and cuttings, the reduction of these widths by the adoption of a narrow gauge, and light rolling stock necessarily leads to a saving in cost of construction, but that this saving is not so great as has been imagined is evident by a comparison of the outlay on the Nilgiri branch line with the estimate for the Carnatic Railway which is now in progress.*

The evils of break of gauge which such a short branch connected with the Madras Railway would entail are noted by the District Engineer, and they seem to be almost conclusive as an argument against its adoption. The disadvantages of inclines worked by stationary engines and ropes may be summed up in few words. It is a system only suited to short and straight lines, not to long and sinuous ones; disarrangement of one part of the rope or machinery stops the whole traffic. The wear of the ropes is immense and the friction great. It has been generally abandoned.

Central-rail systems.—The central-rail system seems on practical as well as theoretical grounds to be best adapted to the circumstances of the Coonoor ghat, and the balance of advantage is certainly in favor of the adoption of the Indian standard gauge of 5 feet 6 inches. Both the Fell and the Rigi system are fully described in Captain Morant's report, and it is unnecessary here to enter into the details of the construction of the lines or locomotive engines. It will be necessary before coming to a final decision on the question of which of the two should be adopted to obtain thoroughly trustworthy information of the results of the working up to the most recent dates of the Rigi system as applied to other mountains in Europe,† and of the Fell Railway at Cantagallo or the Organ mountains in Brazil. I think that Captain Morant has taken a somewhat exaggerated view of the cost of the Fell, as compared with the Rigi

* Are the circumstances the same? I cannot help thinking that when the average of many hundreds of miles is taken for both the Broad and the Narrow Gauge, that the saving on the side of the Narrow Guage will be quite as great as has been imagined. The Nizam's Railway, constructed with great care, and through a country of moderate difficulty only, has cost £9,000 a mile; parts of the Holkar Line, running through similar country, have cost only £5,000. Whenever Broad Gauge lines have been cheaply constructed of late, the extensions have been through *easy* country; the Nilgiri Branch and the B. B. and C. I. extensions are instances of this.—J. H. W.

† Further information regarding the Rigi system, which is proposed to be applied in Switzerland to a gradient of 1 in 12½ on an international line between France and Austria, will appear in a future number. On this proposed line the traffic is estimated at about 450,000 tons per annum, and each engine is calculated to push up a paying load of 60 tons.

Railway when placed on the Coonoor ghat, and that a reasonable deduction from the data available in this country is that mile for mile the Rigi Railway would cost more than the Fell line. Assuming that the former is at a gradient of 1 in 7, and the latter of 1 in 12, I would be inclined to sum up the advantages of the Fell system as follows :—The locomotive is capable of carrying up nearly twice the load per train which is dragged by the Rigi locomotive, consequently it can accommodate more traffic. It is adapted both by gradient and by the mechanical principle of its construction for working at a higher speed than the Rigi locomotive. The security against derailment is greater; the brake power can be more safely applied, and consequently there is more security. The same locomotive can work on the ordinary line with two rails, and the central rail can be discontinued and resumed at intervals. Including rolling stock, the line is mile for mile cheaper than the Rigi Railway.*

Comparative advantages of the Fell and Rigi systems.—In the trial of the locomotive for the Brazil Railway on the Fell principle, 27 tons of paying load were taken up an incline of 1 in 12. The Rigi locomotive cannot take more than 15 tons. On the Fell Railway, a speed of ten miles per hour has been worked up to, and by limiting the load, there is no reason why a greater rate should not be attained. The racking and jar of the machinery which would be induced by working the Rigi arrangement at speed would be very great, as well as the danger of breakage of the teeth of the spur wheel engaged in the rack. The tendency to derailment on curves, &c., is instantaneously checked by the central wheels of the Fell locomotive. The clutches on the Rigi engine must have play, and only come into action in time to resist a dynamical shock. The atmospheric break can be as easily introduced into the Fell as into the Rigi locomotive, and as regards the axle breaks of the Rigi engine these tend to skid the spur wheel, the result of which would be great jar between the rack and spur wheel teeth. In short, the whole success of the Rigi depends on very low speed. The data obtainable in this country

* Are not the objections to the Fell system under-estimated ? The impression left on my mind by all the letters and reports which I read at the time the line over the Mont Cenis was working, was that the complications of the system led to great wear and tear of the engines, which were incessantly in the Shops under repair. Commercially also, the plan was a failure.—J. H W.

An eye-witness thus describes the Fell's Engines on Mont Cenis. "The tear and wear and cost of repair of the Engine stock is excessive. Hardly a journey but wants repair or re-adjustment on the Engines. The queer grinding and tugging and straining and squealing of the locomotive and carriages as they toil up and slide down the steep inclines bespeaks an amount of repair beyond the range of ordinary experience." (*Bombay Builder, April* 1869—p

favor the supposition that, as before stated, the cost of a mile of the Fell line will be less than that of the Rigi Railway. It may be said for the Rigi system that the line is shorter than the Fell line when applied to surmount the same incline, and that consequently the effect of low speed and small loads is neutralized; that the cost of the whole line is much less than that on the Fell plan; and that the amount of steam power which can be utilized for propulsion is not limited by the variable adhesion of the wheels to the rails.

Comparative cost of several Railways.—In the subjoined Statement, page 253, the estimated cost of the several systems of railway worked by locomotive engines, as applied to the Coonoor ghat, is given under several heads of expenditure, and the outlay on the Madras Railway, Nilgiri Branch line constructed in 1869-73, as well as that current or estimated for the metre gauge Carnatic line now in progress, is added. It is considered that ample allowance has been made in the estimate for the greater difficulties of construction on the ghat, and that it may be safely considered that these estimates would not be exceeded.

It is to be observed that the calculations of cost rest on data of an unusually unexceptionable character, that is to say, on the actual cost of work of a similar kind recently executed in this country, and chiefly in the same locality; moreover, while the actual quantities of iron used on the Madras Railway branch line have been taken into account, the cost has been estimated at the exceptionally high market rates of 1873. At the rates current when the line was constructed the cost per mile was actually £1,000 per mile less than that entered in the statement.

The cost of the earthwork and rock excavation for the present ghat road to Coonoor has been recorded, (*vide* page 252,) and there can be no reasonable doubt of the fact that the similar work of benching out the incline for the railroad can be executed for the sum set down, and as regards the other items, it will be observed that a generally large allowance has been made for the difficulties of construction on a steep gradient and for unforeseen contingencies. It is to be remarked, and it is important to bear the fact in mind, that railways in this country can now be constructed at rates far below those originally current, when operations and contracts were all more or less tentative.

Expenditure on New Coonoor Ghat.

Quantity.	Particulars.	Rate.	Per.	Amount.		
	1.—*Benching out.*	RS. A. P.		RS. A. P.	RS.	A. P.
327,655	Cub. yds. earthwork, 1st class,	0 2 0 to 3 0	c. yd.	56,192 12 3		
102,643	„ „ 2nd „	0 3 6	„	22,453 4 0		
38,337½	„ „ 3rd class,	0 4 6	„	10,782 7 0		
14,219⅜	„ „ 4th „	0 5 6	„	4,888 0 0		
16,379	„ raising embankments.	0 2 6 to 4 0	„	4,429 4 6		
37,307½	„ blasting and removing rocks, ...	2 0 0 to 2 8 0	„	80,821 12 0		
16	Mile stones, ...	7 8 0	each	120 0 0		
16	Miles check channel, ..	147 5 0	mile	2,356 14 0		
16	„ levelling the road, ..	300 0 0	„	4,800 0 0	1,86,844	5 9
	2.—*Revetments and parapets.*					
47,108	Cub. yards revetment and parapets, ...	0 12 0 to 15 0	c. yd.	41,021 12 0	41,021	12 0
	3.—*Bridges and Drains.*					
1	Timber Bridge 70′ span, ..	7,600 0 0	each.	7,600 0 0		
1	„ „ 56′ „ ..	5,140 0 0	„	5,140 0 0		
1	„ „ 40′ „ ..	3,677 0 0	„	3,677 0 0		
5	„ „ 20′ „ ..	982 0 0	„	4,910 0 0		
6	„ „ 15′ „ ..	500 0 0	„	3,000 0 0		
25	„ „ 12′ „ ..	375 8 0	„	9,387 8 0		
9	Drains 8′, ...	400 0 0	„	3,600 0 0		
44	Stone covered drains, ..	168 0 0	„	7,392 14 0		
27	„ „ ..	125 0 0	„	3,375 0 0		
16	„ „ ..	100 0 0	„	1,600 0 0		
228	Common drains, ...	14 0 0 to 25 0 0	„	5,402 0 0	55,084	6 0
	4.—*Metalling.*					
15,808	Cubic yards metalling, ..	..	..	13,338 13 6	13,338	13 6
	Compensation for land and sundries, ...	..	..	..	29,628	0 0
	Grand Total, ..	..	..	..	3,25,917	5 3
	Or average cost per mile, Rs. 20,310.					

Statement of the Actual Cost of Railways on the Broad and Narrow Gauge in the Madras Presidency, and of the Coonoor Ghat Road; and the Probable Cost of various systems of Railway Line as applied to the Coonoor Ghat.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Surveys, Preliminary Expenses, and Supervision.	Excavation or Embankment (Formation of Roadway).	Ballasting and Permanent Way.	Masonry Works and Girders.	Stations, Buildings, Gates, and Crossings	Rolling Stock.	Electric Telegraph and Fencing.	Cost of Land.	Contingencies.	Total per Mile for Ghat Line.	Total Mileage on the Ghat.	Total for Construction of Ghat Line.	Extension from Mettapollium to Kullar.	Total cost of Line from Mettapollium to Coonoor.	Interest of Outlay during Construction.	Grand Total, Capital Charge.
DATA.	RS.	RS.	RS.	RS.						RS.	Miles.	£	£	£	£	£
Nilgiri Branch, Madras Railway, 5' 6" gauge, ...	5,760	8,268	45,891	16,271	12,936	11,660	1,616	...	Included in former heads.	...	25	...	..	...	...	...
Trichinopoly to Tuticorin, metre gauge, ...	5,622	4,468	19,393	8,934	3,951	4,981	...	...	463	...	...	...	...	...	...	...
Ghat Road from Kullar to Coonoor, gradient 1-18, 6 yards wide, ...	...	*14,241	...	3,443	...	...	...	...	...	...	...	...	...	...	...	...
ESTIMATES.																
Australian system of ghat railway, viz., heavy engines, rails, gradient 1-29 on Indian gauge,	15,000	20,000	5,000	18,000	9,000	12,000	1,500	500	12,550	1,38,050	25	345,125	50,000	395,125	39,500	434,625
Norwegian narrow gauge light rails and rolling stock, gradient maximum 1-54, gauge 3' 6"	14,000	13,000	20,000	9,000	4,000	5,000	1,500	500	6,700	73,700	48	353,760	50,000	403,760	40,000	443,760
Bell central-rail system, average gradient 1-12 ...	15,000	20,000	70,000	20,000	10,000	15,000	1,500	500	7,714	1,69,708	12	193,655	50,000	243,655	15,000	258,655
Riggi central rack-rail system, average gradient, 1-7, Indian gauge,	17,000	20,000	70,000	20,000	17,140	30,000	1,500	500	8,947	1,96,834	7	125,037	50,000	175,037	11,400	186,437

* Includes the cost of revetment walls and parapets.

NOTE.—The roadway is in all cases calculated for a single line of rails.

Relative Economy of Railway and other Carriage.—Comparatively few years' experience in working the railways in the plains has shown that the ancient modes of carriage and communication compete with them in this country under circumstances, and to an extent which had certainly not been anticipated when estimating the probable returns on the capital invested. The lesson has been taught that it is necessary, when attempting to make such forecasts to ascertain and take into consideration the circumstances of the carriers which may favor them in their competition with the railway, and to make allowance for the prejudices of the people and their distrust of new modes and methods which are attempted to be introduced. The periodicity of the rainy and dry seasons creates an interval, comprising several months, during which agricultural operations are practically suspended. The farmer has to maintain his live stock, and in reality also his laborers, who under the patriarchal system prevailing in the village communities, are attached to, and dependent on the ryots throughout the year. To yoke his bullocks to a cart and to employ them in the carriage of his own produce or that of others to a market is the natural resource of the cultivator, and during the dry season it is obvious that it would pay him so to employ them with a return merely equivalent to their bare subsistence. Where, as in these cases, time is of little value, and for moderate distances, the railway in the plains can offer to the native few advantages over the primitive mode of carriage, and, moreover, the customs and feelings of the people are in favor of the latter, as they retain throughout the custody of their own goods, and the cart is only set aside when the gain of transit by railway is palpable and substantial.

Nature of inquiry necessary.—When prosecuting, therefore, an inquiry into the prospects of a ghat railway as a remunerative enterprise, it is necessary to ascertain, as far as possible, the actual cost to the carriers of the present modes of transport, and the conditions under which they work, and, moreover, to institute a comparison with these methods and transit by railway as respects necessary or minimum charges, which in both cases would yield a fair profit. Such an inquiry is attended with considerable difficulties. Accounts respecting the circumstances of the carriers differ, and it is not easy to obtain thoroughly reliable information respecting their average outgoings and returns.

As respects the railway, the estimate of the cost of construction, and to a considerable extent of maintenance also, must rest on hypothesis.

Enough information has, however, been obtained to establish the fact that the profits on the carriage of goods at present rates, though considerable when considered in relation to the capital outlay represented by the cost of the carts and live stock used, form but a comparatively small portion of the charges which are largely made up of outgoings not susceptible of reduction. The hardships entailed by exposure, and the wear and tear of cattle, and the unequal division of traffic, of which three-fourths is in an upward direction, thus preventing return loads from being obtained in the majority of cases, are all circumstances rendering a reduction of charge to any material extent impossible.*

Cost of maintenance and working of a ghat railway.—The cost of several systems of railway as applied to the Coonoor ghat, together with that of an extension of the present line to Kullar, has been estimated above (*vide* pages 251, 252, 253), and it is now proposed to show what the cost of maintenance and working would probably be in each case, to derive therefrom and from the capital outlay given above the annual charge, which will be considered to be 5 per cent. on that outlay in addition to the cost of working, &c., and to deduce from the data thus obtained and the annual existing traffic the charges on that traffic which must be made to meet the annual railway charge. A comparison of these with the existing rates for carriage up the ghat will indicate pretty clearly what are the prospects of the success of a railway in a financial point of view.

The cost of working and maintaining the existing Madras Railways is shown in the most complete detail in the half-yearly accounts, and it is only necessary to apply the charges under the several heads to the case of the ghat railway, with the due allowance for the circumstances, in order to arrive at what would in all probability be the annual expenditure. The difficulty lies in estimating the allowances required. The annexed Statement shows the expenses incurred annually on the North-West and South-West branches of the Madras Railway, derived from current returns, and under the several heads those which it is estimated would attend the working and maintenance of the system described in the first column. Consideration has been given to the effect of heavy gradients and special construction in increasing the wear and tear of permanent way and the expenditure of fuel, while the economy of working, as compared

* The Railways have not yet beaten off all the traffic down the Bhore and Thull Ghat roads; not very much comes down the Thull Ghat, but there is still a considerable traffic to Bhore Ghat. But as the height to be overcome in the Coonoor Ghat is more than double that of the Bhore and Thull Ghats, there are grounds for believing from a comparison of the two cases that the Coonoor Railway would run the traffic off the existing road.—J. H. W.

rative Statement showing the Actual Cost of Maintenance and Working Expenses of the Madras Railway and the Estimated Cost under the same heads of various systems of Railway applied to the Coonoor Ghat.

1	2		3		4		5		6		7	8	9	10	11
ame of Railway.	*Maintenance of Way, Works, and Stations.*		*Locomotive and Carriage Expenses, except Fuel.*		*Fuel.*		*Traffic Expenses.*		*General Charges, Special and Miscellaneous, Telegraphs.*		Total for Ghat Line.	Miles of Way.	Locomotive Miles.	Ton Mileage.	Total for Line from Mettapolliem to Coonoor.
	Per mile per Annum.	Per Annum.	Per Locomotive Mile.	Per Annum.	Per Locomotive Mile.	Per Annum.	Per Mile per Annum.	Per Annum.	Per Mile per Annum.	Per Annum.					
	RS.	RS.	A. P.	RS.	A. P.	RS.	RS.	RS.	RS.	RS.	RS.				RS.
Railway, ...	1,270	10,96,736	5 6·9	10,80,910	3 8·4	5,84,644	674	5,77,044	532	2,27,617	35,66,951	858	12,64,024	55,606,442	...
class of Railway, e Engine, 1·29 gra-	1,905	47,625	5 6·9	9,000	RS. A. 1 1·28	27,000	674	16,850	532	13,300	1,13,775	25	25,000	4,50,000	1,35,675
gauge, narrow gauge, egian type, ...	1,270	60,960	5 6·9	9,850	0 13·8	24,000	674	32,352	532	25,536	1,52,698	48	27,872	13,37,856	1,74,598
tem, Indian gauge,	2,340	28,080	7 10	7,000	0 11·68	10,500	674	8,088	500	6,000	59,668	12	14,400	2,52,000	81,568
k-rail system, Indi- uge, ...	2,340	16,380	10 7	9,500	0 14·9	13,500	800	5,600	500	3,500	48,480	7	14,462	1,47,000	70,380

e cost of the branch from Mettapolliem to the foot of the ghat for maintenance and working expenses, will be Rs. 21,900 per annum at the Madras rate, and this sum is added in each case to give the total in Column 11.

with the Madras Railway consequent on low speed, absence of all night traffic, smaller ton and train mileage, &c., has not been lost sight of. The estimates of total annual expenditure will, it is thought, fully meet all possible contingencies.

Total annual charges and resulting rates.—In the succeeding Statement the capital outlay for each of the several species of railway lines from Mettapolliem to Coonoor, and the annual charges for interest thereon at 5 per cent. per annum, are entered, as also the maintenance and working expenses from the previous Statement. The total annual charge is thence derived as well as the tariff of rates per ton and per passenger necessary to meet that charge.

The present charges by cart are also inserted.

	Capital Outlay.	Interest on Capital at 5 per cent.	Maintenance and Working Expenses.	Total Annual charge.	*Tariff of Rates to cover Total Annual Charge for journeying from Mettapolliem to Coonoor, or reverse.*				
					Passengers.			Goods.	
					1st class, 2,500.	2nd class, 3,000.	3rd class, 10,000.	Special Rate, Tons 1,500.	Ordinary Rate, Tons 13,500.
Australian system of ghat railway, Indian gauge, heavy engines	£ 434,625	£ 21,731	£ 135,675	£ 35,298	RS 20	RS. 10	RS 1	RS. 20	RS. 12·5
Norwegian narrow gauge, light rails and rolling stock, gradient maximum 1—54, gauge 3' 6"	443,760	22,188	174,598	39,647	20	10	1	25	14·5
Fell system central-rail 1—12, Indian gauge	258,655	12,933	8,157	21,090	10	5	1	15	7·5
Rigi central rack-rail, Indian gauge, gradient 1—7 ...	186,437	9,322	7,038	16,360	10	5	1	15	6·1
Bullock cart or carriage on ordinary ghat road ...	...	...	...	..	2 0	12	2	Tons 3,000 34	15

Summary of conclusions.—It is believed that the estimates which

have been made in this* Report of the present extent of the traffic on the ghat, and its rate of increase in the past and for the future, of the charges with which it is burdened, of the profits of the carriers, the rates at which the several systems of railway could afford to carry goods and passengers up the ghat with ample profit, as well as the cost of their construction and maintenance, are based on evidence which can hardly be impeached, and which if anything tends to create a reasonable doubt as to whether in regard to traffic and returns, present and prospective, they are sufficiently large.

To sum up, the following facts appear to be reasonably established :—

I.—That the total charges on the present annual traffic between Mettapolliem and Coonoor amount to £44,000 at least.

II.—That this traffic has been increasing during the past seven years at an average rate of 11 per cent. per annum, and that it has doubled itself within the last 10 years.

III.—That a railway could be constructed between Mettapolliem and Coonoor sufficient to accommodate the present and any increased traffic which is likely to exist for £260,000 on the Fell system, and for £187,000 on the Rigi system.

IV.—That, in order to yield a return of 5 per cent. on the above capital outlay and pay all charges for maintenance and working expenses in carrying the existing traffic, the Fell railways would require a return of £21,100 per annum only, and the Rigi railway £16,300 per annum.

V.—That the resulting rates per ton and per passenger are such as to render impossible all competition with the railways by existing modes of transit.

A. DE C. S.

Extracts from Report by CAPT. J. L. L. MORANT, R. E., *Assoc. Inst. C.E. and F.R.G.S., District Engineer, Nilgiris, to the Under-Sec. to the Govt., P. W. Dept., Madras.*

The tract of country between Mettapolliem and Coonoor naturally divides itself into two distinct and very different parts.

The first, the almost level piece between Mettapolliem and Kullar ;

* Many of these have been omitted in the Extract.

The second, the abrupt ascent or Ghat up to Coonoor.

For the former a railway like that between Coimbatore and Mettapolliem, which traverses a very similar country, seems obviously the best suited.

But for the latter, must not a very different kind of railway be provided? Would it not be a fatal error to place upon the first place a railway suited only for mountain traffic? Is not a mountain railway quite out of place on an almost level plain? While, on the other hand, surely a railway just suited to the first level portion would not be able to do duty up the steep Coonoor ghat; for special engines and rails, unsuited to level lines, are considered always necessary for working lines over mountains. Moreover the physical nature of the country indicates somewhere at the foot of the ghats as the point where the existing railway ought to terminate, and not at Mettapolliem.

It will then be probably admitted that the present railway ought to be continued from Mettapolliem to Kullar.

I speak under correction, but I believe the Railway Station at Mettapolliem is 100 feet in vertical height above the roadway of the present Bowani Bridge, and that the station is half-a-mile distant from the river. The fall of the natural ground is therefore something like 1 in 27. By erecting a railway bridge over the Bowani, with its floor some 20 or 30 feet higher than that of the present bridge, a gradient of 1 in 33 or of 1 in 37 for half a mile will be obtained. Should this descent be considered too steep, I may mention that on the Birmingham and Gloucester Railway there is an incline for a length of three miles of 1 in 37, up which trains ascend at the rate of 28 miles per hour, and another at Oldham, near Manchester, three-quarters of a mile long, of 1 in 27, both constructed many years ago, besides many others of short lengths, all of which are worked by the ordinary traffic engines of the lines on which they occur. Except the bridge over the Bowani, and the lesser one over the Kullar river, this almost level portion, six miles long, presents, I believe, no difficulties whatever to the construction of a railway.

Kullar being now considered a deadly locality at night, no residences for the railway employés, nor buildings of a permanent nature would now be required there. A small engine could easily convey such railway officials as would have to reside at Mettapolliem from thence to Kullar every morning and back again in the evening.

The cost of this portion would probably be as follows:—

Six miles, at 80,000 rupees per mile					...	...	Rs. 4,80,000
Bridge at Mettapolliem	...	...	...	...	...	„	2,00,000
Bridge at Kullar	...	...	...	...	...	„	40,000
						Rupees,	7,20,000

Or say, Eight Lakhs of Rupees.

No additional rolling stock would be required.

Is the suggestion worth consideration that the Madras Railway Company be called upon to complete this portion themselves, on condition that Government undertake the Ghat Railway? The additional traffic, which a line up to Coonoor would naturally bring to the whole of their branch from Pothanoor to Kullar, would probably be held by the Company to be worth this additional outlay.

With regard to the ascent up to Coonoor it seems desirable, in the first place, to cast aside the idea of utilizing either of the present roads.

The new ghat is 16 miles long. It has 12 zig-zags, many of which terminate in precipices of rock or at the edge of large ravines or streams. Its gradient is 1 in 18½. It possesses 32 timber bridges, of spans varying from 12 up to 70 feet, none of which could bear a railway. It has numerous very sharp curves, occurring mostly at precipitously rocky parts, all of which would have to be made easier for a railway. And it is only 18 feet wide, except in a few precipitously rocky parts, where it is merely 12 or 15 feet wide.* This width would be insufficient for a railway and road together. The carriage road over Mont Cenis, on which Fell's Railway was first tried, was 32 feet wide, of which the railway occupied the 12 or 15 *outer* feet, and there was besides a fence between the rail and roadway.† Many parts of the outer edge of the existing ghat road, both in the shape of stone walls and earthwork, would not bear a railway. If the whole of the new ghat be given up to a railway, what road, other than the almost impracticable old ghat, are persons to use during its construction, or when needing repair? Moreover, the first

* The best line for this ghat would have started from the foot of the Kotergherry ghat, which is only two miles distant from Mettapolliem. Thence it could have risen, without lengthening the whole distance between Mettapolliem and Coonoor, at a gradient of about 1 in 22, by the St. Catherine's Falls Valley, and at the foot of Lambs-Rock up to othe Coonoor Bridge, where it now ends. This line would not have involved more than three zig-zags, and might possibly have been accomplished with only one. It was advocated by Major Law, I believe, when tracing the present line.

† Civil Engineer and Architect's Journal, Vol. XXVIII. (1865), page 234.

two miles at the top of the ghat would need to be kept permanently open for carts, as these are Coonoor's only access with the important sub-districts of Kartairy and Colacumbay. The next three miles run alongside of large coffee estates, and are used for carting manure. There are also other parts, especially about the middle of the ghat, which accommodate quite a local traffic. To attempt to draw this small local traffic, moving very short distances, into a railway running along the road, would create inconvenience, and necessitate numerous petty stations, and consequent expense in providing for it, quite disproportionate to its quantity and value.

The old ghat, which has been very unscientifically lined out, is 9 miles long and possesses various gradients, from nearly dead level up to 1 in 6, in some parts its gradients running the reverse way. It cuts across the new ghat nine times, and has a great many very sharp curves. Most of its drains are of a very poor description of jungle wood, and some of its streams are unbridged.

Neither of these roads seem therefore at all suited for a railway. Hence it will be perhaps admitted that a railway of any description would of necessity require an entirely new road-way to be made for itself.

With regard to the description of railway suited to the case, four kinds may be brought to notice, upon each of which it will be necessary to make some remarks.

I. Railways worked up steep inclines in the usual way by the adhesion of smooth wheels on smooth rails.
II. Narrow gauge lines, on gradients seldom exceeding 1 in 50.
III. Steep inclines worked by stationary engines.
IV. Centre-rail railways with locomotives for working on very steep inclines.

I. *Railways worked up steep inclines in the usual way by the adhesion of smooth wheels on smooth rails.*—These are worked on grades very seldom exceeding 1 in 25. On such grades they travel at the slow speed of about eight miles per hour. The engines have to be of a special kind, very powerful and heavy. The rails must also be weighty. The wear on the permanent way and consequent cost of up-keep are great. And there is no special security against derailment. Railways of this description have been laid in various parts of the world, but those of the steepest grades have been almost entirely confined to the United States.

So long ago as 1851, a line worked by locomotives was laid over the

Alleghany Mountains. It had an inclination of 1 in 45½ for 11 continuous miles, and, after winding amongst the summits of the mountains for 20 miles, it descended on the western side with an inclination of 1 in 45½ for 9 continuous miles. The passenger trains travelled at a speed of 15 or 20 miles per hour, and the goods trains at a speed of 10 or 15 miles per hour. The curves were frequently sharp.* Such a line laid on the Coonoor ghat would be nearly 40 miles long, and could not be ascended under 3 hours and 20 minutes.

Other lines, with gradients of 1 in 17½, and with curves of 300 feet radius, have also been laid, but their Engineers advocate them only for temporary use while the construction of tunnels underneath or more permanent works are in progress.

As is well known the Americans run great risks with locomotives worked on steep inclines, and it has not seldom happened, when the rails have been greasy, that the engine and train have slid backwards with locked wheels from the top to the bottom of the incline.

To show how the inconveniences of continuous steep gradients are felt, it may be mentioned that on a long incline of 1 in 26, near Liege, a perfect system of stationary engines had been in use for many years. The Belgian Government, feeling the inconvenience of that system, had abandoned it, and substituted the locomotive, but such was the uncertainty of the power in meeting the difficulties of the incline that the stationary engines were again resorted to.†

And these steep inclines are attended with a heavy cost for working expenses, amounting in some cases where the traffic was mainly dragged upwards to 12 pence per ton per mile, which can only be considered justifiable on a long line of generally easy grades heavily worked. To give an instance: the returns of the Semmering incline, in Austria, which cost nearly £100,000 per mile, show that the working expenses exceed the receipts, so great is the cost of working over 22 miles with gradients of 1 in 40 and 1 in 45, and with curves of 10 chains radius.‡ And a further illustration is afforded from the returns published by the German Government, where it will be found that on an incline of 1 in 38 at Aachen Ronheide, on the Rhenish Railway, 63 per cent. of the rails had

* Proceedings of Institute of Civil Engineers, 23rd November, 1858.

† Proceedings of Institute of Civil Engineers, 23rd November, 1858.

‡ Mr. Vignoles at Institution of Civil Engineers on the 8th November, 1862.

to be renewed in 5 years; and on the Western State Railway of Saxony, on gradients of 1 in 40 up to 1 in 100, the former predominating, 58 per cent. of rails with steel tops had to be renewed in 7 years, 50 trains passing daily over the line; whereas on many other German lines, whose gradients do not exceed 1 in 100, 2 per cent. only of the rails have had to be renewed in five years.* The life of the rails on the Bhore Ghat Great Indian Peninsula is only 4 years.

It will not, I trust, be considered here out of place to briefly illustrate the influence which *curves* exercise on the paying load. It has been found that at a speed of 45 miles per hour, the traction resistance on a line having curves under one mile radius, at the ratio of one curve to 22 miles, was greater by 20 per cent. than on a practically straight line; and on the South Devon line in England, the engines took seven loaded wagons up an incline of 1 in 41 on straight portions, but on coming to curves of 15 chains radius one of the wagons had to be removed.†

From experiments made by the General Superintendent of the New York and Erie Railroad in 1865 on an engine weighing nearly 30 tons with about 18 tons on the pair of driving wheels of 5 feet in diameter, the resistance of curves was found to be $\frac{1}{2}$ lb. per ton per degree of curvature per 100 feet.‡

It may also be as well to point out a well known fact, often lost sight of, that the steepness of the grade exercises a very appreciable influence on the consumption of fuel and steam, an important matter in India, where fuel is dear and water at times scarce. This is roughly illustrated in the following Table, by disregarding friction and by supposing that only

Incline.	Resistance to be overcome.	Adhesion weight required.	Adhesion weight in fraction of gross weight.
1 in 50	2 tons	10 tons	$\frac{1}{10}$
1 in 40	$2\frac{1}{2}$ tons	$12\frac{1}{2}$ tons	$\frac{1}{8}$
1 in 20	5 tons	25 tons	$\frac{1}{4}$
1 in 10	10 tons	50 tons	$\frac{1}{2}$

gravity has to be overcome, that an adhesion of one-fifth can at all times be secured, and that the gross weight of the engine and train is 100 tons.

* "Engineering," Vol XII., 1871, pages 261 and 347.

† Proceedings of Institute of Civil Engineers of 30th November, 1858.

‡ Proceedings of Institute Civil Engineers, Vol. XXVIII. (1868), page 269.

The above, of course, is an extreme illustration, but it helps the more plainly to show that the adhesion weight available being simply that of the locomotive, the percentage of paying load which it is possible to take up diminishes, very rapidly as the steepness of the gradient increases. While in another direction it will be found that in order that the boilers of a mountain railway locomotive engine may be of moderate dimensions, it is essential that a very slow speed be maintained; because the amount of adhesion which any given locomotive boiler-power is capable of using up depends entirely upon the speed at which the engine travels. For example: if, by the evaporation of a given quantity of water per unit of time, when travelling at a speed of 10 miles per hour, an adhesion weight of 30 tons can be utilized, then, if the speed be reduced to two miles per hour, it will be possible, with the same expenditure of steam, to use up an adhesion of 150 tons, or five times the former amount.

Moreover, an engine, when on a severe incline, changes its position so much as to alter materially its running condition. Attempts to provide for this point have been made in many mountain engines, by building them expressly for working inclines, but the matter is in an incipient stage. It will doubtless not escape notice how beautifully the Rigi engine meets this difficulty. The Fairlie Engines also have sloping boiler tubes.*

It is, perhaps, here necessary, in concluding this portion of my letter, to observe that the above remarks, trite as some of them may appear, are made solely with reference to the Coonoor ghat. The traffic on this ghat will not probably for some years be nearly so large as that, for example, on the Western Ghats of India near Bombay. But some have thought that a railway might be placed on the Coonoor ghat, of a similar kind, only with a steeper grade, and therefore of shorter length, and hence accommodating a much smaller but still sufficient traffic. In that case the points above illustrated will have to be carefully considered. Most eminent Engineers of the present day, so far as the matter has at present been developed and where large traffic has to be carried, prefer to trust to the adhesion of a smooth wheel on a smooth rail rather than resort to any more complicated expedient. But they prefer this obviously with gradients and curves involving on the Coonoor ghat an outlay which the traffic would not justify.

II. *Narrow gauge lines on gradients seldom exceeding* 1 *in* 50.—The

* *See* "Engineering," Vol. XVIII. (1874), page 142, and illustrated double sheet.

term narrow-gauge is intended here to apply to those lines with a gauge less than the English standard of 4′ 8½″. Of these I have tabulated in the Appendix (No. II.) three, merely as types. There are of course many others in different parts of the world.

The Soudan Railway is the first proposed to be constructed in that part of Egypt, so that it involves no break of gauge. It has just been commenced.*

The Norway narrow gauge lines are numerous, and exist with those of a broader gauge (4′ 8½″). In 1871 the number of miles of the narrow were nearly double those of the broader gauge lines. But in 1872 a line of 32½ English miles in length of a gauge of 3′ 6″ between Christiana and the Port of Drammen was opened. There were upon it some sharp gradients and curves, which required adequate engine power. It was soon found that the engines and rolling stock were insufficient. The weight drawn by each engine (its own weight not included) was only 33 tons, as compared with 80 tons drawn by the engines on the 4′ 8½″ gauge lines. It was therefore enacted in the Norway Parliament that for the future the State railways should only be made on the standard gauge of 4′ 8½″; and on that gauge the new State line, 126 English miles long, *viâ* Federikhald to the Swedish frontier is being constructed.†

In the sister kingdom of Sweden the standard gauge (4′ 8½″) is the favorite. About five years ago a discussion took place respecting the continuation of the gauge of 4′ 8½″, owing to the lines on that gauge being considered too expensive. The Swedish Government at length decided to continue the standard gauge, and some of the narrow gauge lines were subsequently changed to the standard gauge, and lines which had been proposed on a 3′ 6″ were being executed on a 4′ 8½″ gauge. The Swedish engineers now state that they see no reason to regret this decision. The Austrian State engineers, with the facts and opinions of the Swedish engineers before them, have also adopted the same views. There were in Sweden, in 1873, 2,400 miles of railway open and in construction. Of these 83 per cent. were standard gauge lines, and 17 per cent. narrow gauge. Of the latter 5 per cent. were unconnected and independent lines, and 12 per cent. were joined with the main system. These latter amounted in length to 258 miles, divided into 8 branches; but

* For a general description of this Railway, *see* "Engineering," Vol. XV., 1873.

† Mr. Bidder at Institute of Civil Engineers, Vol. XXXV., page 247.

of these only 82 miles had been then constructed, involving only one break of gauge in all Sweden, the inconvenience caused by which, after having been felt for eight years, had led to no more breaks of gauge being allowed.*

The Festiniog Railway in Wales is, I believe, the only instance of an important narrow gauge line conveying passenger traffic in the whole of England. Its gauge is only 1′ 11½″. Some particulars regarding it will be found in Appendix No. II. It is an independent line, quite unconnected in one direction with any other. It was constructed under special and peculiar circumstances. The main traffic of the line is in slates, and the trucks have to be taken right up to where the slate is quarried, and where no large wagons can go. The slate is thus unavoidably let down steeply inclined planes in narrow wagons, and, if the gauge of the main line had been broad, must have been reloaded into broad gauge wagons. On reaching Port Madoc, the end of the line, the slates have to be transferred from the wagons to the ships alongside the quays. This very narrow gauge Festinoig line is therefore the best for conveying slates to the port of shipment, and is thus well adapted to the circumstances of the case. In another direction this narrow gauge line meets the Cambrian Railways. It carries slates, minerals, and general goods. At the junction the slates are shifted by hand, the minerals are tipped from the narrow to the broad truck, and the general goods are lifted from one truck to the other by means of cranes. By far the larger portion of the traffic is in one direction.†

In very narrow gauge railways the rails are subjected to greater strains by the oscillation of the rolling stock; because the narrower the gauge the greater the angle through which the vehicles are canted laterally, owing to any accidental elevation or depression of one of the rails; and thus the inequality produced in the loads, on the springs, and on the rails on either side, is much more felt. For these reasons the greatest possible care has been taken with the permanent way of the Festiniog line, and the rails are jointed with very stiff fish-plates of a peculiar kind. Very great attention has also been paid to the rails laid on the curves; and the line is always carefully kept in first-class order. It will probably be

* Proceedings of Institute of Civil Engineers, Vol. XXXV., pages 337 and 530.

† Narrow Gauge Railways, by C. E. Spooner, and Proceedings of Institute of Civil Engineers, 11th April, 1865; as also "Civil Engineer and Architect's Journal," Vol. XXIX. (1866), pages 211 and 12.

admitted that a permanent way of such perfection in unattainable in India.

But, independent of the inherent objections to which narrow gauge lines are open, it is necessary to consider, in the case of the Coonoor ghat, the evils attendant on a break of gauge, if any line be made up to Coonoor and Ootacamund of a narrower gauge than that which now terminates at Mettapolliem. I trust the gravity of the subject will be considered a sufficient excuse for my enlarging upon it.

The late Lord Dalhousie, in 1850, thus addressed the Court of Directors:—"The British Legislature fell unconsciously, and perhaps unavoidably, into the mischievous error of permitting the introduction of two gauges into the United Kingdom. The numerous and grievous evils which arose from that permission are well known, and will long be felt throughout all England. The Government of India has it in its power, and no doubt will carefully provide, that however widely the railway system may be extended in this empire, in the time to come, these great evils shall be averted, and that uniformity of gauge shall be rigidly enforced from the first."

Sir John Hawkshaw, and other eminent English engineers, have often said, that "the evils of break of gauge have all over the world proved to be too serious to be borne." And it is not unreasonable to suppose that these evils will be much more felt in India than in England, on account of the comparative inefficiency of the Natives at the stations, and the pilfering and bribery which so commonly goes on.

It is well known that in England, Brunel's Great Western broad gauge (7′) has almost entirely disappeared. One of the last places where it broke with the standard gauge was at Gloucester. Here the transfer of the traffic was so great an evil that the South Wales and Midland Railways arranged for allowing 20 miles of mileage to compensate for that break; and Mr. Molesworth, the Consulting Engineer for Indian State Railways, considered it equivalent to more than 20 miles.* The damage to salt by this break of gauge was valued at one shilling per ton, where the value of the salt was 30 shillings per ton.† And in all cases the delay caused by the break of gauge was never less than one day, and very frequently it was two days.

* Proceedings of Institute of Civil Engineers, Vol. XXXV., pages 312 and 393.
† Ibid, page 393.

In the colony of Victoria a proposed line touched existing railways at three points, where if a break of gauge was involved, the Traffic Manager estimated the cost of transferring traffic at £3,900 per annum.*

Fell's Mont Cenis line (which will be entered into more fully hereafter) between the French system of railways at St. Michel and the Italian system at Susa, is another instance of the evil of break of gauge. It was constructed on a narrower gauge than that of the two railways which it connected. The traffic was chiefly in passengers, and to them the inconvenience experienced was most serious; but to the development of the goods traffic it was much more detrimental. Each ton of goods cost eight pence in transhipment, and a day's delay, the station arrangements being very expensive and complicated † "In fact," says M. Brunlees, "if there had been a great amount of goods to deal with, or had an army with its baggage, commissariat, ammunition, &c., made its appearance, there would have been inextricable confusion."

Even in India examples are not wanting of the evils of break of gauge. The Indian Branch Railway Company made two branches to the main line of the East Indian Railway, one from Nulhattie to Moorshedabad, and the other from Cawnpore to Lucknow. The former was made on a good existing road on a narrow gauge, but the traffic on the line dip not answer the expectations of its projectors. The latter was on the standard Indian gauge, and returned a good dividend. I have been favored with the following remarks on this subject by one of the leading Madras merchants, who also possesses land on these Hills: "The line I alluded to yesterday is the little railway that runs between Arconum and Conjeveram. It is a trumpery business, constructed principally for passenger traffic; but it would I believe have had a fair share of produce had it been practicable for the carriages to run through to Madras. I believe it has never paid even working expenses. I think I heard that Government had ordered this railway to be altered to the Indian gauge, as it is proposed to extend the line to Pondicherry; but I am not quite certain. My experience of the undesirableness of a break of gauge is derived from many conversations I have had with Natives as to the reasons they do not more largely make use of the Conjeveram line for their produce. Their invariable reason was the breaking of

* Proceedings of Institute of Civil Engineers, page 373

† Mr Brunlees at Institute of Civil Engineers, Vol. XXXV., page 357.

bulk. They preferred, they said, to get bandies to come all the way to Madras rather than have bags of seed and dubbers of oil unpacked twice by the railway authorities. Of course, where engineering difficulties make a break of gauge of great consequence, my opinion would give way, but where practicable I would most strongly advocate only one gauge. And I speak as a merchant, who entrusts his goods to the railway, and who has experienced how detrimental it is to Produce, breaking bulk. We had a long time of it when the P. and O. Steamers only went as far as Alexandria and Suez: now that the vessels go direct home we find a great difference in the condition of our cargo."

I believe the only reason ever advanced for adopting a narrow gauge is the belief in its superior economy. But it has been clearly proved, in many instances, that the saving in first cost of construction between a narrow gauge line and one on the standard gauge is not large, and Mr. Molesworth has so reported to Government, in comparing the Indian standard (5′ 6″) with the metre (3′ 3″) gauge. Between a broad and narrow gauge of the same capacity there need be no difference in the depth of the ballast, nor in the weight of the rails, nor in the scantling of the sleepers, not in the engineering setting out of the line and preparation of plans and estimates. The only difference would be in the length of the sleepers, and in the widths of the cuttings, embankments, bridges and culverts. Mr Brunel's Great Western Railway, with a gauge of 7 feet, cost only £400 more per mile than the Great Northern, with a gauge of 4′ 8½″, although Mr. Brunel added four feet in width to all the works, in order to increase the future capabilities of the line.* In the colony of Victoria, plans and estimates were made for 220 miles of line on the two gauges of 5′ 3″ and 3′ 6″, and the difference came to £350 per mile.† Gauge has in fact a very insignificant influence on the cost of a railway, the real criterion of expense being the carrying power.‡

It must also be pointed out that, though the data are not complete, there is much *primâ facie* evidence to show the probability of extra expense being involved in working narrow gauge lines. In regard to *fuel*,

* Proceedings of Institute of Civil Engineers, Vol. XXXV., page 430. Life of I. K. Brunel, by Isambard Brunel, 1870, page 129.

† Proceedings of Institute of Civil Engineers, Vol. XXXV., page 373.

‡ Without advocating the narrow gauge, I must say that I think justice is hardly done to its cost. I have no great faith in estimates, and believe that in estimating the narrow gauge cost, there is an insensible something, such for instance as the lightness of all the parts, and the care with which they are handled which eludes calculation. The Government of India must now have before them sufficient *facts* to prove this point.—J. H. W.

the consumption on the Festiniog line was stated by Mr. Spooner, the engineer of the line, and a great advocate for narrow gauge railways, to be 50 lbs. per train mile, or double that of an ordinary passenger engine on an English (4′ 8½″) line, and 24 per cent. beyond that of the Madras Railway (5′ 6″). Mr. Molesworth reported to Government that the *working expenditure* per train mile on the Festiniog was double that of the English, and three times as much as that of some of the Irish Railways, on which latter the rates of labor would probably more nearly resemble those of a remote district like Festiniog.*

Moreover, on a narrow gauge railway, accommodating the same traffic as one on a broader gauge, the sidings would necessarily be longer, and consequently both their first cost and maintenance greater. And the narrow gauge would obviously require more rolling stock, and more numerous trains, entailing increased wear and tear of moving parts, such as wheels, axles, boxes and springs.

The Indian standard broad gauge, of 5′ 6″, which was so deliberately fixed by Lord Dalhousie for the whole of India, is more advantageous for articles of bulk, compared with their weight, such as tea and cinchona bark, because the width of the carriages must bear a fixed proportion to that of the rail gauge, otherwise they become unsteady.

In the particular case of the Coonoor ghat, we have the branch line from Pothanoor up to Mettapolliem already constructed on the same gauge as that of the main line between Madras and Beypore. The length of this branch is 25 miles. Is it worth while now to break the gauge at Mettapolliem, and to bear all its attendant evils, for the sake of perhaps saving a sum of 1½ lakhs of rupees on the first construction of the remaining 23 miles of the branch up to Ootacamund, while probably an increased cost in future years of maintaining and working the whole of this branch will have to be borne?

Whatever be the kind of railway decided upon, the conclusion at which I hope Government will arrive, will be to allow no break of gauge, but to continue the Indian standard right on to Coonoor, and thence at some future date to Ootacamund, and perhaps to Nediwuttum.

III. *Steep Inclines worked by Stationary Engines.*—Examples are not wanting of inclines worked in the usual manner, with large drums, brakes,

* Proceedings of Institute of Civil Engineers, Vol. XXXV., pages 400 and 401. Narrow Gauge Railways, by C. E. Spooner.

wire ropes and stationary engines. There is a long one, with curves, at a gradient of 1 in 12, on the San Paulo Railway in Brazil,* and another very steep one opposite Pesth in Hungary. On the railway now under construction over the Andes across South America, to connect Buenos Ayres on the Atlantic with Valparaiso on the Pacific Ocean, one such incline, perfectly straight, at an inclination of 1 in 8, is proposed for a length of only half-a-mile, to be worked with a single stationary engine.† This method is best suited for short lengths and straight lines. Here it works economically. But it is considered utterly unsuited for general use, its radical defect being that the disarrangement of any single length of it, by any accident, stops the travel on the whole line. It may be compared to a chain, the failure of any one link of which will render the whole useless. It possesses also the danger (more likely perhaps to occur in India, owing to the action of the climate on the rope) of the hauling wire-rope breaking. Rankine states the wear of wire ropes to be from 67 to 100 per cent. *per annum*. Moreover, locomotives can do the work as well, and are more convenient. For these reasons, the system of working inclines by stationary engines and rope-traction has been quite given up in England where passengers have to be conveyed, and is confined almost entirely to the haulage of goods, minerals, and coals. The late Mr. Berkeley—formerly Chief Engineer of the Great Indian Peninsular Railway—first laid out on the Bhore ghat an incline to be worked by a stationary engine, but on the matter being referred to the late Mr. Robert Stephenson, he advised that this plan should if possible be avoided, even though its omission were attended with a considerable augmentation of the cost of the work.‡

On a tortuous and long line, such as the Coonoor ghat renders necessary, other systems seem preferable. But the subject need not be further enlarged upon, as I presume Government will not view it with favor.

IV. *Centre-rail Railways with locomotives for working on very steep inclines.*—Of these, I believe, there are only two systems, the leading feature of both being the provision of a centre rail in addition to the two ordinary carrying rails.

* Proceedings of Institute of Civil Engineers, Vol. XXX., page 29.

† Report on the Transandine Railway, by Robert Crawford, C.E.

‡ The Railways of India, by Captain Davidson, R.E. (1868), page 272.

1. *The Fell Centre-rail Railway.*
2. *The Rigi Ladder-rail Railway.*

1. *The Fell Centre-rail Railway.*—This system consists of a centre-rail raised nine inches above the two side carrying rails. The locomotive is provided with two pairs of horizontal gripping wheels, which are driven up against the centre-rail by a pair of pistoned cylinders worked by an engine quite independent of that which drives the vertical wheels. Adhesion is thus gained from the horizontal wheels almost equal to that obtained from the ordinary vertical wheels thus making the engine almost equal in effect to one of twice the weight. This system was patented many years ago, but was never carried into practice on any large scale until the year 1865, when it was laid on an excellent existing zig-zag carriage road over the Mont Cenis Pass of the Alps between St. Michel on the French and Susa on the Italian side. Here it was worked for a few years in quite a temporary manner, while the celebrated tunnel underneath it was in progress. Captain Tyler, R.E., of the Board of Trade, long connected with railways, was ordered by the English Government to be present at Mont Cenis to witness certain trials which were made with this system before the railway over the mountain was completed.* From his report the following facts are drawn. The trials were made on a piece $1\frac{1}{4}$ miles long, rising the whole way with a mean gradient of 1 in 13, with one sharp curve of two chains radius. The gauge was 3′ $7\frac{5}{8}$″, and the rails weighed 75 lbs. per lineal yard. Several trips up and down this experimental line were made with two different engines. With one engine a gross load (exclusive of engine) of 14 tons was dragged up, at $8\frac{1}{2}$ miles per hour, in weather very favorable to the rails. Captain Tyler reported, that "this engine labored under serious disadvantages, its machinery being too much crowded together for convenience in readjustment and repair; its boiler power being insufficient; and the oil from its machinery falling upon the horizontal wheels deprived them to some extent of their power of adhesion." The second engine worked better, and took up the same load as before, at $10\frac{3}{4}$ miles per hour. At the time when Captain Tyler reported, the projectors of the line proposed to provide for the carriage of 132 passengers and 88 tons of goods daily, by running three trains each way, as per following Table, the average gradient of the line being 1 in 25·6, and the steepest 1 in 12.

* *See* "Civil Engineer and Architect's Journal," Vol. XXVIII. (1865), page 294.

No. of Train.	No. of Passengers with Luggage.	No. of Tons of Goods.	Rate of Travel in miles per hour.	Gross weight of Train, exclusive of Engine.
1	40	..	11	16 tons with 1 engine.
2	26	20	8	40 „ 2 engines.
3	..	24	6¼	48 „ 2 „
Total one way,	66	44		
Back Journey,	66	44		
Grand Total, ..	132 Passengers,	88 Tons.		

The temporary line over Mont Cenis was estimated to cost, exclusive of stations, &c., £6,720 per mile, but Captain Tyler states that the cost of a permanent and independent line, with a wider gauge and better curves, will be £20,000 per mile, the permanent way alone costing at least half as much again as that of a mountain railway without the centre-rail. On the completion of the Mont Cenis tunnel in 1871, the summit line was taken up, and the experience gained during the five years in which it worked showed that the defects in the system were so serious as to greatly disappoint the hopes which had been held by many persons when it was first started. It consequently proved a financial failure.

In 1873 it was again revived under more favorable circumstances over the Organ Mountains in Brazil, where it is reported to have dragged 15 tons of cargo and 22 passengers up an incline, about 8 miles long, having gradients varying from 1 in 20 to 1 in 12, and curves of 140 feet radius, at a little over 6 miles per hour.* The permanent way is the same in construction as that which was laid over Mont Cenis. The gauge is $3' 7\frac{5}{16}''$. But the engines have been improved.† Before the rolling stock was shipped to Brazil, some experiments were made with it at Malton in Yorkshire.‡

* "Engineering," Vol. XVII. (1873), page 167, and Vol. XVIII., (1874), page 396.

† *Engineering* thus remarks on the Locomotives for the Cantagalto Line:—"We consider that Messrs. Manning, Wardle and Co., have done the best which is to be done for the centre rail system, and although they have produced a locomotive, which, from its complication, we can only admire as a specimen of workmanship, yet we believe that the complication to which we object has been reduced to the least amount compatible with the system on which the engine is constructed." and again, "The engine weighs empty about 25 tons, or about 30 to 31 tons in working order. This is a heavy load to carry on two pairs of wheels, particularly as from the very short wheel base, and consequent great overhang at each end, the normal load on each pair of wheels is liable to be increased to a very important extent when running. Indeed, when passing over a road in moderately good order, we should expect the load on one of the axles to frequently exceed 20 tons.

‡ "Engineering," Vol. XVII., (1873), page 429.

It may be briefly here stated, that the experiments took place on an incline half a mile long, with a gradient of 1 in 12, except in one short part which was 1 in 11. There was only one sharp double curve with a radius of 85 feet on the P in 11 grade. The engine, *working both horizontal and vertical wheels*, took up, over the 1 in 12 part of the incline only, first a gross load of 52½ tons, or (excluding engine) of 22$\frac{3}{10}$ tons, or a paying load of 13½ tons, at a speed of 10 or 12 miles per hour. A second time it took up on the same gradient a gross load of 73½ tons, or a train load of 43½ tons, or a paying load of 27 tons, at a speed of 8 miles per hour. The engine was then *worked only with the ordinary vertical driving wheels*, and first took up over the whole half mile, on the gradients of 1 in 12 and of 1 in 11, and over the sharp double curve, a gross load of 42 tons, or a train load of 12 tons, or a paying load of 7½ tons. A second time, the boiler pressure being increased, it took up, over the 1 in 12 gradient only, a gross load of 52½ tons, or a train load of 22½ tons, or a paying load of 13½ tons, sand being applied to the bearing rails to increase adhesion. The engine was then *worked with the horizontal gripping wheels only*, and, after being started with the vertical driving wheels, carried up a gross load of 52½ tons, or a train load of 22½ tons, or a paying load of 13½ tons. But although the weather was very favorable, owing to the centre-rail being slippery from oil droppings from the machinery, the horizontal gripping-wheels slipped from time to time, notwithstanding that their pressure on the centre rail was estimated at 40 tons. They had therefore to be assisted occasionally with the vertical driving wheels. This crucial test brought out the weak points in the system. A comparison of Captain Tyler's report made in 1865, and of the description of the trials at Malton in 1872, show that the inherent defects in the system exhibited themselves on both occasions, and have not as yet been overcome. These defects are, complicated machinery, insufficient boiler power, oil droppings from horizontal wheels falling on centre-rail and thus depriving both of much of their adhesion, and the great amount of friction involved in the mid-rail machinery, producing great wear and tear of working parts, and thus in the practical daily working of the system making it costly and unreliable.* I have quite recently received a letter from a London correspondent, who has at my request been kindly making enquiries into the matter, and

* *See* "Engineering", Vol., XIV. (1872), page 8.

he says, "The Fell system does not pay. It travels faster than the Rigi, but involves great wear and tear of working parts."

Mr. Mitchell also asks this pertinent question: "On ordinary railways, however well constructed, there are irregularities in the surface of the rails which create oscillation in the trains. In the Fell system it appears that the centre rail must be inflexible, the horizontal wheel biting in proportion to the steepness of the grade. Did the oscillations of the train caused by the irregularities of the side rails not tend to disturb the rigidity which was necessary for the proper working of the centre rail?*

And Mr. Lloyd remarks that there was one thing in M. Fell's engine, admirable as it was, which struck him would cause difficulty in practical operation on a railway abroad—that was the extrems intricacy of the machinery. Simplicity was an essential element in all things connected with a railway in countries distant from the great centres of industry.†

It is now necessary to consider the cost of the Fell system if placed on the Coonoor ghat between Coonoor and Kullar. Here it will be some 12 miles long, with an uniform gradient of 1 in 12, will possess one zig-zag, and will cost, at Captain Tyler's estimate, with an addition of one-third for freight of rails, &c., £26,666 per mile. Hence the 12 miles will cost £319,992, or nearly 32 lakhs of rupees, without including the cost of railway stations and rolling stock.

2. *The Rigi Ladder-rail Railway.*‡—The Rigi is an isolated mountain in Switzerland near Lucerne. Its summit is about 4,500 feet above the Lake. A few years ago its average number of visitors totalled 40,000 annually. It used to be ascended by a zig-zag bridle road, and the ascent took 3 or 3½ hours. A railway to improve this communication was designed by M. Riggenbach. The line is 3½ miles long, and the maximum gradient, which extends over one-third of the whole length, is 1 in 4, the other gradients varying between that grade and 1 in 6, except in some few places, where the line is purposely made almost flat. The curves have a radius of 8½ chains. The line is formed almost entirely by benching on the sloping side of the rock, with occasional revetment walls on the outside. The line consists of a very stiff and strong centre wrought-iron rack-rail, formed like a ladder, in addition to the two usual bearing

* Proceedings of Institute of Civil Engineers, Vol. XXVIII. (1868), page 259.

† *Ibid* XXVI. (1866),—page 349.

‡ For a description of this Line and System, *see* Article No. CXXVII. of "Professional Papers of Indian Engineering," [2nd Series].

rails. The permanent way is constructed with great care and stability, being secured from any possible slipping of the wooden framing, by masonry foundations built into the formation below at intervals of 400 feet. The locomotive has naturally many specialities of design. Its boiler has been made vertical, with vertical tubes, and covered with a dome, from the centre of which rises the chimney. The axis of the boiler is not placed perpendicularly to the base line of the engine, but is inclined to the perpendicular at an angle of about 13°. The effect of this is to cause the boiler to be upright or nearly so when running on the line. One consequence of this arrangement is, that the locomotive must not be turned, but must always have the same end highest, whether running up or down. The two side-bearing wheels are not keyed on to the axle, but run loose like ordinary road carriage-wheels. The centre driving cogged wheel, which is most carefully cut out of cast steel, is keyed firmly on to the middle of the axle. Thus the engine shaft drives, by means of spur wheels, the main axle, and the cogged wheel thereto attached, taking fast hold on the teeth of the fixed rack, forces the whole machine to mount the incline.

Various precautions are adopted to secure safety. *First*, If a hard substance should by chance get between the teeth of the rack, the action of the driving pinion upon it would have a tendency to lift up the engine, when a slipping-off sideways might possibly follow. To meet this liability, at each end of the locomotive are firmly fixed a pair of strong angular jaws, which loosely embrace the upper flanches of each side of the centre rack-rail, and, in the event of the wheels being lifted off the rails, the jaws or hooks catch against the flanches, and hold the vehicle in its place. *Second*, To guard against the danger of the train running down the incline by its own gravity, the engine is provided with no less than *three* independent means of checking and governing its motion. i, An axle-brake, which, when put in action, holds the driving cog-wheel firmly and prevents its turning and so engaging in the rack. ii, A similar axle-brake which acts on the two side bearing wheels. iii, A peculiar mode of working the engine by introducing atmospheric air when running down hill, which has the effect of offering a considerable resistance to the motion, whereby the force of gravity is to a large extent neutralized, and the speed thoroughly regulated. Dr. Pole says he saw the driver, when the engine was going rather too fast, touch slightly the cock handle, which regulates the use of the atmospheric air, and instantly the speed was checked.

Each passenger carriage is also furnished with a peculiar cog-wheel brake (similar to the one attached to the engine) which, when worked, becomes set fast in the centre rack-rail and stops the carriage. The carriages are not attached to the engine, so that, in case the latter should get out of control and run away, no harm would result to the carriages. In ascending, the carriages are pushed up, and in descending, they follow the engine by their own weight down the incline.

The Rigi railway has now been opened for four years, and has been found to work well, no accident or interruption having occurred in its service. A description of this railway (from which the above has been condensed) was read before the Institution of Civil Engineers in England by Dr. Pole, F.R.S., in April 1873;* and in the subsequent discussion Sir John Hawkshaw considered, that "many of its details were ingenious and novel, and that the railway displayed much constructive cleverness." And Mr. Thornycroft held it "to be a bold scheme well carried out." I have also received some letters on this subject from a gentleman now in London, who resided for some years at Coonoor, and is well acquainted with the Coonoor ghat, and who has also seen the Rigi railway several times. He says, Dr. Pole told him he considered the Rigi principle by far the best yet introduced for steep gradients, and he was much struck with the wonderful combinations for safety they had hit upon in the making of the line. He adds, "I was at Vienna last month, and went up the Kahlenburgh, a very high hill in the neighbourhood, from which you have a splendid bird's-eye view of Vienna. This hill (4,000 or 5,000 feet high) is ascended both by a wire-rope rail,† and by a rail on the Rigi principle. I went up by the former and down by the latter, and quite agree with Dr. Pole that ropes are not things to trust passengers to, even though they are double, and that the rack-rail is by far the best and safest for steep gradients. The grades on the Kahlenburgh line are from 1 in 9 to 1 in 15." I may add that since the Rigi railway was made, the same system has been extended to other parts of Switzerland, and has also been introduced into Germany, Austria and Italy. And I take from "*The Architect*" of so recent a date as the 21st of last November, the following paragraph: "A railway is projected to be constructed along the side of Snowdon on the plan of the Rigi line in Switzerland. Notices

* Proceedings of Institute of Civil Engineers, Vol. XXXVI., page 102.
† See Engineering, Vol. XVII. (1874), page 269.

have been issued of a bill to be brought before Parliament next session for that purpose. The line will commence near Llanberis railway station, and terminate at the well-known spring about 100 yards from the summit."

With the above information before them, I trust Government will be pleased to admit that the principle of the centre ladder-rail railway, as applied on the Rigi mountain, has proved and been accepted as successful, and has after an experience of five years, developed no objectionable features.

It will now be necessary to apply the Rigi principle to the Coonoor ghat. The Coonoor bridge is about 1,500 yards in vertical height above Kullar. If the Rigi railway ascended the ghat at an uniform gradient of 1 in 7, the length of the line would be just six miles. The position of the Coonoor bridge with reference to Kullar is such that this line could not probably be laid between these two fixed points at any much steeper grade than 1 in 7. But it will be safer here to assume that it will rise at an uniform gradient of 1 in 8 and be 7 miles long. This circumstance, while increasing the length and consequent cost of the whole line, gives some very important compensating advantages. At a gradient of 1 in 7, the Rigi travels at 6 miles an hour, and carries more than twice the paying load which it pushes up on a grade of 1 in 4, on which it travels at only four miles an hour.

The Switzerland single line cost at first, all told, including stations, rolling-stock, sidings, &c., £15,152 per mile. The Coonoor ghat is not so steep as the Rigi-mountain, but, in order to cover freight to India and other additional expenses, it will be safer to assume that on the Coonoor ghat the Rigi line will cost 33 per cent. more, or £20,203 (Rs. 2,02,030) per mile. The Rigi however is on a gauge of 4′ 8½″, while, in order to avoid breaking gauge with the existing line, which I propose should be extended to Kullar, it must be put on the Coonoor ghat with a gauge of 5′ 6″. This will increase the cost of a portion of the permanent way, and involve slight alterations in the rolling stock, which *in any case* would not be the same as that on the Rigi, for the conditions of traffic on the Coonoor ghat are somewhat different. For the additional cost in permanent way, rendered necessary by widening the gauge, £1,000 per mile may be allowed. For the change in the rolling stock, to suit a wider gauge and altered conditions of traffic, £500 per mile will suffice. And £800 per mile will cover the cost of additional sidings and of anything else that may be needed. Hence is obtained the mileage rate of Rs. 2,25,030,

which gives for the seven miles of the ghat railway a total of Rs. 15,75,210, or *sixteen lakhs of rupees.*

The mileage cost of this railway may be arrived at in another way.

Cost per mile in English sovereigns.	£
1. *Railroad.* Benching hill-side to form for rails a way 26 feet wide, *for double line,* including bridges and portion of ballast, will *at* 2½ *times the cost of the new Coonoor ghat road* come to— ...	5,000
2. *Permanent Way.* This M. Riggenbach states costs £4,400 per mile. One half of this will meet the cost of the 3 rails delivered at Mettapolliem, at £17 per ton, the rest sufficing for sleepers and portion of ballast. But it will be safer to add 50 per cent. to M. Riggenbach's figures, to cover additional cost of wide gauge and freight, &c. The permanent way will thus cost—	6,600
3. *Rolling Stock.* 7 Engines at £1,800 each, ...	12,600
21 Passenger Carriages, of three classes, at £320 each, ...	6,720
7 Goods Wagons, at £203 each, ...	1,400
£20,720	
Add 50 per cent. for wider gauge, freight, &c., ...	10,360
7)£31,080*	
Thus the share of one mile for Rolling-stock will be	4,440
4. *Stations.* 2 large, at £3,000 each, ...	6,000
2 small, at £2,000 each, ...	4,000
7)£10,000	
Thus share of one mile for Stations will be, ...	1,430
5. *Sidings.* Share for one mile, ...	2,500
6. *Contingencies,* at 12 per cent., ...	2,397
Therefore total cost per mile on Coonoor ghat, ... Rs.	£22,367

The cost for seven miles will thus be Rs., 15,68,000, or as before, *under* 16 *lakhs.* Hence it may be safely assumed that the cost of a single line of the Rigi railway placed on the Coonoor ghat, with a way wide enough throughout for a double line of rails, and with all additions required for starting the line, will not cost more than sixteen lakhs of rupees.

I have not taken into consideration the compensation which may have

* If the Madras Railway have wagons with brakes to both pair of wheels, could not these be worked over the incline, thus saving all transhipment? The engines will cost more than estimated, and the carriages too, I think. Third class carriages on B. B. and C. I. recently constructed, 25′ 6″ long and 8′ 6″ wide, provided with brake power cost Rs. 3,050. If special wagons are required, 7 will be insufficient.—J. H. W.

to be given for land taken up from private individuals by this railway, as it is impossible to determine this figure with any accuracy until the line is actually staked out. The amount will be affected by the length of time which elapses before the railway is begun, for land is yearly rising in value, and the area of its cultivation is increasing. In the case of the new Coonoor ghat road, it amounted only to Rs. 8,000 in cash. It must not be forgotten that compensation for land is a common factor to all the railways which may be proposed for the Coonoor ghat, and will be least in the case of the Rigi system, on account of its shorter length.

Nor have I taken into account the cost of the working expenses of the line, as this obviously depends greatly on the quantity of traffic, *i. e.*, the receipts. In the case of the Rigi, the working expenses were one-third of the receipts. The wear and tear in this system are very small owing to its slow speed, and the happy mechanical combination of all the working parts.

I have also purposely abstained from entering into details regarding the alterations in all the rolling stock, which an increase in the gauge and the altered conditions of traffic on the Coonoor ghat will obviously render necessary. The centre ladder-rail system was applied to the Rigi mountain to suit the peculiar nature of the traffic there. The circumstances of the Coonoor ghat are to a certain extent similar, but they differ in other respects. In applying therefore this system to this ghat, the details of the rolling stock will have to be drawn up afresh, and will necessarily differ from those obtaining on the Rigi. It would be beyond the scope of this report to consider them further, beyond saying that the necessary alterations can easily be carried out without increasing the weight on each bearing wheel.

It must now be shown that this railway is capable of conveying up and down the Coonoor ghat the *maximum* load that is likely to come to it on any one day. One locomotive on the Rigi railway pushes up a gradient of 1 in 8, 144 passengers with their luggage, or 12 tons of goods, and travels at the rate of six miles per hour. Supposing that up and down the Coonoor ghat on any one day the conveyance of 864 passengers and of 408 of goods has to be provided for, the following Table shows that this can be done with five engines, with the requisite number of passenger carriages and goods wagons, &c., formed into five trains, following each other up and down at intervals of five minutes, allowing each train 20

minutes at both Coonoor and Kullar to fill the boiler and obtain fresh fuel, &c. To simplify the Table, the two mid-stations, which will perhaps be needed on the ghat, are omitted. Only a few trains need stop at these stations, and, with sidings and other arrangements, they need cause no interruption to the general service, or in any way upset the figures given below.

Stations of Arrival and Departure.	Quintuple train, one train starting 5 minutes after the previous one.	Number of Passengers with luggage.	Number of tons of goods.	Time.
From Kullar to Coonoor, *up*, ..	1	288	36	6 to 7-10 A. M.
„ Coonoor to Kullar, *down*,	2	...	60	7-30 to 8-40 „
„ Kullar to Coonoor, *up*, ...	3	144	48	9 to 10-10 „
„ Coonoor to Kullar, *down*,	4	...	60	10-30 to 11-40 „
„ Kullar to Coonoor, *up*, ...	5	...	60	12 to 1-10 P. M.
„ Coonoor to Kullar, *down*,	6	144	48	1-30 to 2-40 „
„ Kullar to Coonoor, *up*, ...	7	...	60	3 to 4-10 „
„ Coonoor to Kullar, *down*,	8	288	30	4-30 to 5-40 „
		No. of Passengers.	No. of tons	
Possible number *per diem*, ..		864	408	

The above traffic is probably much in excess of present requirements, so that a single line would suffice for some years. It is only given in this way to show the capabilities of the line. Very seldom would so heavy a traffic in one day need to be met. The capacity of the line could be increased by employing a greater number of locomotives on the single line, and hereafter the line could be laid with a double rail. Moreover, the Rigi railway has been constructed to meet a heavy passenger traffic and a small tonnage of goods. Its bearing rails weigh only 22 lbs. per lineal yard, its locomotive only 15 tons. I am informed, by a gentleman who has seen it, that there is now working near Vienna, a railway on this same principle, with larger engines and carriages, dragging up a larger paying load per train, and travelling at a quicker pace. The time might come on the Coonoor ghat, when the light rails and engines should be replaced by those of a heavier kind accommodating a much more extensive traffic. Thus it appears that the centre ladder-rail system suits both the comparatively small traffic of to-day, and can be expanded to compass the much larger traffic of to-morrow.

If uniformity of gauge be maintained throughout the Mettapolliem branch, goods of all kinds could be conveyed all the way from Madras to Coonoor and *vice versâ* without breaking bulk. The goods vans for the ghat traffic would possses no peculiarities, nor be so light (weighing as they do four tons on four bearing wheels) as to prevent their being attached to the Madras train running at speed on a wide gauge. With regard to passengers, the first class would probably prefer changing into the saloon carriages of the Madras railway, which would be out of place on the ghat line. For the other two classes no change of carriage would be necessary. The seats might be suspended like those on certain steam vessels, so that the passengers always retain a perpendicular position. These carriages would be sufficiently large and weighty to run easily at speed over the Madras line. All the Rigi carriages as before pointed out, are provided with peculiar cog-wheel brakes, which can at pleasure be made to engage into the centre rack-rail.* These brakes are sufficiently elevated above the level of the bearing rails to form no impediment to the carriages being run at speed along a more level line. The goods wagons need not have these brakes.

It will now be well to meet certain possible objections which may be started against the Rigi system when applied to the Coonoor ghat.

First. Its cost.—M. Riggenbach states it cost per mile £26,000, whereas Dr. Pole says, "The capital of the company was £50,000, which sufficed for the first establishment of the railway, but the large development of the traffic has rendered necessary the doubling of $1\frac{1}{2}$ miles of the line, the provision of more stock, the erection of enlarged stations, *workshops*, which have increased the outlay to about £60,000." Elsewhere he says, "the railway is $3\frac{1}{3}$ miles long." This set against £50,000, gives a mileage rate as aforesaid of £15,152. A gentleman wrote to me from Lucerne before he had read Dr. Pole's paper thus: "The total cost of the Rigi Railway including stock, was $1\frac{1}{4}$ milions of francs, or say £50,000; but," he adds, "*it could now be laid for a much less sum, as, this being the first of the kind, many experiments had to be made.*" He further states, "the line is double for about one half the way, and single at the top and bottom." Thus the only conclusion at which to arrive is, that M. Riggenbach's statement refers to *a double line*

* Then it will be necessary that both 1st, 2nd, and 3rd class change carriages; if this is not done the stock estimated for would be insufficient.—J. H. W.

with workshops, and that the cost of a single line at first starting is that which Dr. Pole states it to be.

Secondly. Its slow speed.—This is six miles an hour. This defect is more than compensated for by the short length of the line. The speed though absolutely slow, is relatively quick. This will be seen in the tables which are appended. For, the gradient at which it can be laid being much steeper than that of any other line, its whole length, where the same elevation has to be reached, will be shorter. It thus possesses the advantages of requiring a smaller number of miles to be constructed in the first instance, of a smaller number of miles to be constantly worked and kept in repair, and of a much slower speed, involving less wear and tear, being maintained in order to reach the summit of any given elevation in the same time as on any other kind of railway.

Thirdly. Its small paying load.—This objection must be admitted, but its force will be much lessened by considering the circumstances of the case to which it is proposed to be applied. No one would advocate the Rigi system for a place with a large and heavy traffic. But does such exist on the Coonoor ghat? The truth is just the reverse. The only doubt that arises in any one's mind is whether the amount of traffic can be shown to be large enough to justify a railway at all. If the Rigi is cheaper than any other railway when laid on the Coonoor ghat, and accommodates all the traffic, though it be small, which that ghat, is likely to carry when the line is opened, there seems little more to be desired. Dr. Pole states of the Rigi, "The total number of trips made up and down during the season* of 1872 on this single line, was 2,875; the total distance run was 23,000 miles; the *maximum* number of passengers in one month was 15,461 up, and 14,354 down (or 29,815 altogether); and the number of locomotives in use was five." This was on a line with a gradient of 1 in 4. Whereas the line proposed for the Coonoor ghat will be only half as steep, and will carry more than twice the paying load.

Fourthly. Its peculiarities make the necessities for uniformity of gauge less felt.—It may also be objected that the evils of a break of gauge, upon which I have purposely enlarged in a former part of my letter, are not of such great moment in this case, where a railway of a peculiar kind with light rolling stock is proposed to be placed on the Coonoor ghat, on

* Believed to be only four or five months long.

which the traffic will be largely composed of passengers. This objection may perhaps to a limited extent be sound. But the following considerations must be weighed. By first, and perhaps by second class passengers, the inconvenience to themselves personally will probably be not grievously felt. But the changing of their luggage will be considered a nuisance. The third class passengers, the numbers of whom will largely exceed* those of the other two classes, will be greatly annoyed by a break of gauge. Most of this class will be coolies with small head loads coming up to the Hill markets or to estates. Many of them now travel on the existing line between Karamuddy and Mettapolliem. In the certain confusion and hustling, which will accompany the change of carriages at the latter place, they will probably lose or have injured some of their loads, whether these loads are placed in their own carriages or in a separate van. The ghat railway would doubtless convey from the Coimbatore District up to the Hills live stock, such as poultry of all kinds, and perhaps sheep and bullocks. In the conveyance of these, and of tea, coffee, cinchona bark, grain, and of all other goods, the inconveniences will be as much felt as in all other parts of the world. And it will not be disputed that this kind of traffic will increase every year after the opening of the railway. With regard to the rolling stock, it must be pointed out that most of it need not be very different from that on the Madras Railway. It is the engine and not the carriage which is so different from the ordinary type. The Rigi carries up a small paying load, but its carriages weigh four tons on four bearing wheels, and hold 54 passengers. The fear of dangerous oscillation to the rolling stock of the Rigi system, if allowed to traverse the wide gauge of the Madras Railway at speed, need not be entertained. The far lighter rolling stock of the Festiniog line on a gauge of less than two feet, travels at 30 miles an hour.

In now comparing the two centre-rail systems—the Fell and the Rigi —as applied to the Coonoor ghat, we find:

1. That the Fell costs double the Rigi system.
2. That the Fell system will be 12 miles long, and will ascend the ghat in two hours, while the Rigi system will be seven miles long, and will ascend the ghat in $1\frac{1}{2}$ hours.

* I think not; about three carriage loads of 3rd class passengers in every passenger train that travels over the Bhore and Thull Ghats, have to shift into and out of the compound Ghat brakes, both at the head and foot of the incline: no complaints are made, and the inconvenience is not apparently very great.—J. H. W.

3. That the Fell locomotive is deficient in boiler power and complicated, producing great wear and tear of working parts; while the Rigi locomotive is simple, light, and efficient.
4. That the Fell carries up twice the paying load which the Rigi pushes up.
5. That the Fell system will certainly necessitate one zig-zag; while the Rigi can have none.
6. That the Fell system has been only twice applied and has proved no financial success; while the Rigi system has been worked steadily for five years, has been, and is being extended to several countries, including England, and has in every case paid large dividends.*

Should Government desire to be more fully informed, they will find tabulated in three Appendices, information obtained from the best sources regarding existing mountain railways. For the sake of comparison, I have entered approximately their length, cost, and time of ascent if placed on the Coonoor ghat.

It may be well here to recapitulate the points which I have endeavoured to make good in this letter.

I. For the present, the desired improvement on the existing means of communication between the railway terminus at Mettapolliam and the Nilgiri Mountains should be for prudential reasons extended no farther than Coonoor.

II. In view of what has already occurred on the Coonoor ghat, the improvement to be effected, whatever it be, should be of a lasting and permanent character, which will not require to be superseded by something better after a few years.

III. No break of gauge should be allowed in the continuation of any railway system from the present terminus, which will be the centre of the branch line from Pothanoor whenever the line is extended as far as Ootacamund.

IV. The existing railway should be continued to Kullar—the foot of

* With the experience of the Bhore and Thull Ghat inclines before us, there are strong grounds for believing that the Rigi cog-wheels system will be much safer to work than the Fell system. The co-efficient of friction for iron skidding on iron is, I am sure, very much less in descending than is usually allowed for by Morin, Rankine, and other great authorities; and in this country, where the working staff cannot always be so reliable as in Europe, it is of great importance to adopt that system, which as far as can be judged offers the best chances of safe working—J. H. W.

the mountain—in an exactly similar way to that in which it has been constructed between Pothanoor and Mettapolliem.

V. To ascend the Coonoor ghat by any system of railway, neither of the existing unsuitable roads should be used, but the permanent way should be laid on an entirely new railroad: and,

VI. The Rigi ladder-rail railway should be applied to the Coonoor ghat as being the cheapest and best suited to the circumstances of the case.

.J .L .L M.

EP INCLINES.

ls on Smooth Rails.

Number.	N	Length if placed on the Coonoor ghat in miles.	Approximate cost if placed on the Coonoor ghat in Rs.	Probable time occupied in ascending Coonoor ghat in hours.	REMARKS.
		Miles.	*Rs.*	*Hours.*	
1	I	36	Lakhs 158	3½	This railway has one reversing station or zig-zag. Took 4 years to study ground and explore, and 7 years to construct the line. Rails weigh 85 lbs. per lineal yard.
2	2	40	260	3½ or 4	Crosses the Noric Alps. Takes up trains of 165 tons gross weight, engine and tender included. Took 6 years to explore for line, and 5½ years to construct it A tortuous line with numerous curves. This line which is laid with a double way throughout, cost £98,270 per mile.
3	3	32	...	3	Draws trains weighing 80 tons.
4	3	22¼	...	2½	4′ 8½″ gauge steel rails laid on the heavy inclines. Drags up trains of 200 tons gross weight.
5	3	20	...	3 or 4	The engineer of this line advocates it only for temporary use. The cars dragged up when full weigh 43 tons. All the cars are provided with a break to each wheel, and a breaksman is stationed at each end of the car. The whole distance worked by the mountain engine was 8 miles, over which the average gradient was 1 in 29½.

	Length if placed on the Coonoor ghat in miles.	Approximate cost if placed on the Coonoor ghat in Rs.	Probable time occupied in ascending Coonoor ghat in hours.	REMARKS.
	Miles.	*Rs.*	*Hours.*	
s with 18″ ' diameter. ıg without uel, weighs	16	...	2	A very crooked line.
	35	Lakhs 70	Probably 3 or 4	Has three zig-zags or reversing stations. This line traverses a very rugged and precipitous country. Its earthworks and rock cutting have been unusually heavy. Gauge 4 8½″. Double headed rails weighing 75 lbs. per lineal yard.
with four x pairs of ani bogies.	25	Lakhs 62½	Probably 3	Gauge 4′ 8½″.
th vertical the perpen- It has a It has two 16″. They rn a special g axle, and ll wheel is meter, thus for the one ″ in diame- ft, but run of the best axle. It is eeth. This ith a centre otive works rack rail. ns provided n, and pre- ines.	7	Lakhs 12	h. m. 1-10	On 1 in 4, one locomotive can push 54 persons with luggage. On 1 in 10, 180 persons with luggage. Bearing rails weigh 22 lbs. per lineal yard. Centre ladder rail weighs 121 lbs. per lineal yard. Permanent way consists of cross sleepers 8′ × 7″ × 6″ laid 2′ 6″ apart from centre to centre, and united firmly into a strong frame by longitudinal timbers 7″ × 6″ on each side, 6½′ apart from centre to centre. This framing is strongly secured at intervals of 400 feet to masonry foundations built into the formation below. Gauge 4′ 8½″.

untries. This is not absolutely correct, but is near enough for purposes

0.

Number.	Length if placed on the Coonoor ghat in miles.	Approximate cost if placed on the Coonoor ghat in Rs.	Probable time occupied in ascending Coonoor ghat in hours.	REMARKS.
1	*Miles.* 44½	*Rs.* Lakhs 36	*Hours* 2¼	An easy line, 3′ 6″ gauge, rails weigh 50 lbs. per yard.
ager 127 mo- two ons. ch a	48	Lakhs 21	2 and h. m. 2-40	Gauge 3′ 6″. Mr. Pihl does not recommend a less gauge than 3′ 6″, except under very special circumstances. Rails weigh 38 lbs. per lineal yard, except on steep inclines, where they weigh 42 lbs. Width at formation level in cutting and embankments is 13 feet. Ballast 8′ wide at top, and 1′ 9″ in thickness.
ach heel gine pair ions d.	60	24	2	Is a single line. Gauge 1′ 11½″. In cuttings, roadway at formation level only 8 feet wide, on embankments 10 feet. Double-headed rails weighing 49 lbs. per yard. The permanent way is in first-class order and well drained. The carefully made rails are almost rigid.
bes. ar at nter lin- do cial and el is hus e of dia- but the It eth. h a mo- ntre pro- and	7	12	h. m. 1-10	On 1 in 4, one locomotive can push 54 persons with luggage. On 1 in 10, 180 persons with luggage. Bearing rails weigh 22 lbs. per lineal yard. Centre ladder-rail weighs 121 lbs. per lineal yard. Permanent way consists of cross sleepers 8′ × 7″ × 6″, laid 2′ 6″ apart from centre to centre, and united firmly into a strong frame by longitudinal timbers 7″ × 6″ on each side, 6½′ apart from centre to centre. This framing is strongly secured at intervals of 400 feet to masonry foundations built into the formation below. Gauge 4′ 8½″.

eep Inclines.

	Length if placed on the Coonoor ghat in miles.	Approximate cost if placed on the Coonoor ghat in Rs.	Probable time occupied in ascending Coonoor ghat in hours.	REMARKS.
	Miles.	*Rs.*	*Hours.*	
rder 14 er, con- surface our cy- ke for ameter. iers 11" al coup- . overn- sadvan- ded to- air; its t traffic ry falls to some	21 if on grade of 1 in 25.	Lakhs 42	2 or 3	This railroad was laid over the outside skirting of the high road of the mountain. The road was 32 feet wide, 13 of which the railroad occupied. Gauge 3' 7⅛". Rails of the I Section, weighing 75 lbs. per lineal yard. To provide for the carriage of 132 passengers and 88 tons of goods daily, three trains were run each way, one train carrying 40 passengers with luggage, a second train carrying 26 passengers and 20 tons of goods, and a third train carrying 24 tons of goods; the first train being taken up with one engine, the other two with two engines each. Captain Tyler, R.E., estimated that this same line, if made permanently and on a railway of its own, would cost £20,000 per mile.
f coup- pair of pair of plicated ripping cel base g order rizontal of each revers- ary and	12 at a con- tinu- ous gradi- ent of 1 in 13.	Lakhs 24	Nearly 2	Gauge 3' 7$\frac{5}{16}$". Rails of which there are three, weigh 65 lbs. per yard. Centre rail being carried 9" above the carrying rail. The total haul on this line, including weight of engine and cars is 73 tons.
l tubes. cular at ll water o cylin- do not l crank is con- 8·7" in giving he driv- diame- but run he best r is 25". This a centre	7 at a con- tinu- ous gradi- ent of 1 in 8.	Lakhs 12	h. m. 1-10	On 1 in 4, one locomotive can push 54 persons with luggage. On 1 in 10, 180 persons with luggage. Bearing rails weigh 22 lbs. per lineal yard. Centre ladder-rail weighs 121 lbs. per lineal yard. Permanent way consists of cross sleepers 8' × 7" × 6", laid 2' 6" apart from centre to centre, and united firmly into a strong frame by longitudinal timbers 7' × 6" on each side 6½ apart from centre to centre. This framing is strongly secured at intervals of 400 feet to masonry foundations built into the formation below. Gauge 4' 8½".

No. CLXVI.

AN INDIAN ENGINEER'S NOTES ON THE (LONDON AND BIRMINGHAM) GRAND JUNCTION CANAL.

[*Vide* Plate XXXVIII.]

Section of Canal.—SECTION, of course, not always constant; very common section that shown in *Fig.* 1: 35 to 40 feet surface width, and centre portion, for a bottom width of 14 feet, always kept dredged out to full depth of $5\frac{1}{2}$ feet.

Towing-path on one bank only, and not maintained with any particular care, but generally sloped gently to outside to give surface drainage a run off. In places, shifted from one side of canal to the other for convenience or economy of maintenance. At all heights above water from 3 inches to 24 inches. Very common way of revetting inner slope along line of wash is shown in *Fig.* 1. Lower bricks laid dry, the water soon depositing a strong mud cement between them: upper course in mortar. Bricks not stepped back, slope being given in foundation. Some of this revetment laid two years ago, on a part of canal much used, is quite as good as new. Only object of keeping towing-path low, that I could ascertain, is to reduce expenditure on maintenance of inner slope above water line. Engineer allowed that it became flooded and very sloppy in many places during wet weather.

Disposal of flood water.—The rise of surface level from heavy rain is very slight, owing to the ample provision made for escape of storm water over bye-washes and "tumbling weirs." A heavy thunder storm will only raise the canal pound near Blisworth (16 miles long) from 2 inches to 3 inches. The 'tumbling weirs" are of the most primitive description, either in long

slopes of masonry or rough stone, or in long *steps* of masonry; but head of water on them, as a rule, very trifling. Some bye-washes at locks of an objectionable design, leading flood water from above lock right into lock chamber, where it must cause accumulations of gravel and silt.

Rain-fall.—Maximum rain-fall, 27 inches; minimum, 17 inches; mean, 22 inches to 23 inches per annum.

Loss from Lockage, &c.—Loss from lockage and leakage in dry weather from summit level estimated at 130 locks a week, which would give a current loss of $\frac{130 \times 9000}{7 \times 24 \times 60 \times 60}$, or very nearly 2 cubic feet per second.

Pumping Engines.—In order to supply this loss, pumping engines employed to lift water from reservoirs at Little Tring to summit level of canal. Another part of canal supplied by engines pumping water from the "green sand." Engines at Tring, are old, Boulton and Watts, low pressure; one 70 H. P., but working expansively up to 85 H. P.; another 60 H. P., working similarly up to between 70 and 75 H. P. The larger pump working at time of my visit, and said to be lifting 240 gallons of water 70 feet per stroke, 11 to 10 strokes per minute;

Work done. $\frac{240 \times 11 \times 70 \times 10}{33000} = 56$ H. P. working power: this would give a modulus of efficiency for the engine of $\frac{56}{85} = 0{\cdot}66$. No guides or brackets to steady pump beam, which must have been 80 feet long; beam of fir 11 inches × 11 inches, scarfed in 20 feet lengths, worked *very* steadily and smoothly; almost entire absence of vibration and concussion.

Pump Valve. Bucket of pump, 30 inches diameter; valve, Harvey and West's patent, of which main feature is (*vide Fig.* 2) a hollow iron cap sliding up and down pump shaft over a space of about 3 inches, and fitting down closely on to a circular plate at bottom of shaft. Cap A rises and admits water as pump shaft descends, closing down on to plate BC as pump shaft is raised. Man in charge of pump said, that when the old butterfly clacks were in use, the concussion at closure of valve was perceptible all over engine-house; that each butterfly valve cost £5 to gear, and lasted only 6 months, while the new valve would last 50 years. But they were very apt to get out of order if any sand came in with water, as collar jammed, or else wore away very rapidly. With coal at 9*s.* a ton (!), water cost 1*s.* a lockfull at summit level.*

* 6*s.* 6*d.* a lockful according to Chairman of Company.

THE GRAND JUNCTION CANAL.

Fig. 1
Section of Canal

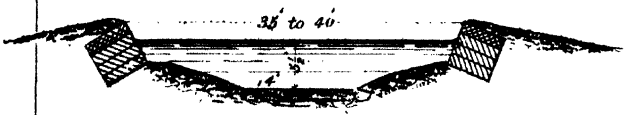


Fig. 2
Cap Valve

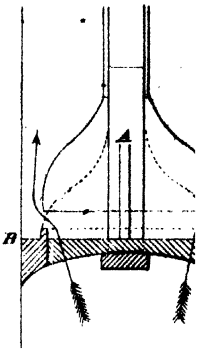


Fig. 3
Section of Aqueduct

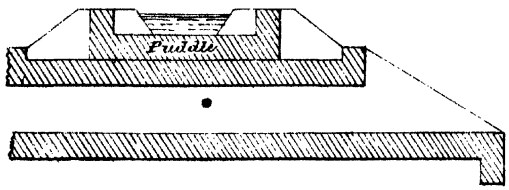


Fig. 4a.
Lock-gate details

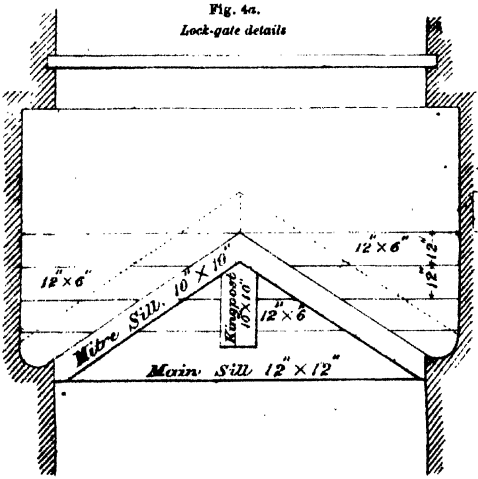


Fig. 4b.
Lock-gate details

A *Section of Mitre Sill on square*
B *Bottom Bar of Gate*

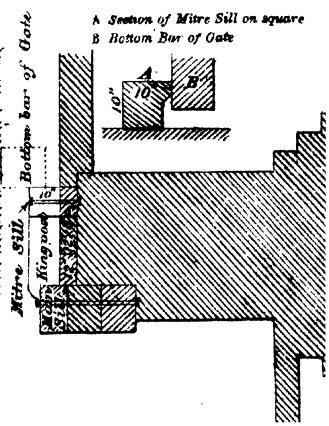


Fig. 5
Fender Beam

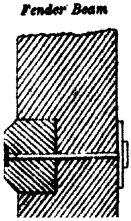


Fig. 6a.
Lock and Side Ponds

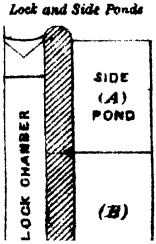


Fig. 6b
Lock and Side Ponds

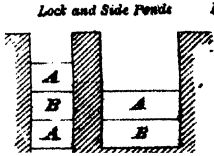


Fig. 7
Bottom bar of Lock-gate

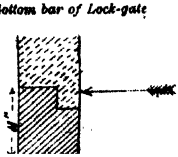


Fig. 8
Boat being hauled



Bridges.—Canal bridges of various spans from 14 feet to 24 or 25 feet. Headway varying from 8½ to 10½ feet in older bridges; towing-path not carried under arch, but the later bridges, especially those built at other people's expense, provide for towing-path under arch, and give plenty of headway.

Aqueducts.—Could not see any plans of the old masonry aqueducts on line, but there did not seem to be anything particularly noteworthy about them. Canal Engineer appeared to object strongly to iron troughs on account of the leaking at junction of masonry and iron, and the only design for an aqueduct that I saw was exactly similar to the common Indian plan, carrying the earthen embankment across the drainage, and providing good puddle walls and bottom for channel, (*vide Fig.* 3.)

Locks.—Locks varied in height of lift, and depth of water in chamber with tail gates open. Waste of water caused in some flights by heights of lift not having been kept uniform. General dimensions of locks 88 feet length; 14 feet breadth; and 3 feet 10 inches to 5 feet 6 inches depth of water in chamber; lift varied from 6 to 8 feet. General dimensions of masonry walls, &c., in locks of 6 feet lift seemed about the same on those of our Ganges Canal locks of 8 and 10 feet lift. Owing to excellence of foundations all over line of canal no concrete used anywhere, so far as I could ascertain.

Flooring of Head bay.—In the older locks, the top of lift wall covered by a strong timber platform, with timber main and mitre sills, as shown in *Figs.* 4*a*, 4*b*. These now being re-placed by a cut stone flooring (in place of 12 inch × 6 inch beams), iron mitre sills, and timber main sill. The latter, in some cases, curved, but no great importance attached to cambering the beam. *In all cases*, however, the space over which gates swing kept 10 inches at least below top of mitre sill, and 4 inches to 6 inches below under side of bottom bar of gates, so that these swing clear of all gravel and rubbish. As soon as any gravel collects in this recess under gates, stop planks are dropped into grooves cut for the purpose in side walls of head bay, water is run off and recess is cleared out. For tail gates, it becomes necessary either to drop in stop planks below the gates and pump the chamber dry, or if pound below be a small one, and water is plentiful, the water is run off from whole pound.

Fender beams on lock walls: projecting 2½ inches from wall face: anchored to back of wall by iron rods with nuts and washers: *bevelled edges, (vide Fig.* 5*).*

Filling Locks.—No side culverts used to fill locks, unless where side ponds used, and in a design for a new lock, where they were introduced, they were shown as discharging into lock chamber under lift wall. Not nearly so good a design as ours on Ganges Canal, where they discharge through side walls of chamber. But owing to excellent workmanship of gates, leakage is reduced to a minimum, and side tunnels are perhaps not required, as by working gate sluices alone lock can be filled in three minutes, emptied in three minutes, and a boat can clear lock in eight minutes.

Hollow quoins, iron faced, batter outward, $\frac{1}{4}$ inch to the foot. Anchoring plate for collar of heel post of gate very strong solid casting, tied firmly back to massive stones. Is not attached to iron facing of hollow quoin, (which is tied to masonry by independent anchoring bolts and plates, and is let into main sill at bottom). When they *are* connected, jars and shocks received by collar plates are found to shake facing of hollow quoin lose.

Side Ponds.—Owing to scarcity of water one out of each set of double locks has been converted into a side pond. Locks were doubled, just as railways commenced working, with an idea of accelerating traffic, and competing with railroads. This of course proved unavailing, and double locks doubled expenditure of water, so now side ponds take their place, saving half a lock full of water each time lock is used, (*vide Figs. 6a, 6b*).

Lock gates.—Owing to cost of water for lockage, every effort is made to reduce leakage, and that through lock gates has certainly been reduced to a minimum. Old gates consisted of 2-inch planking, spiked on to 8-inch cross bars (as on Ganges Canal,) and were found to leak so much that it has paid the Company well to substitute for them the new solid gates described below. With these, moisture is barely visible on down-stream side of closed tail gates with 12 feet head of water on upper side. Being fitted with balance beams they swing so easily that a child can open or close them when the head of water is the same on each side.

Heel post, oak, 12 inches × 10 inches at bottom., battering out $\frac{1}{4}$-inch to 1 foot, to fit hollow quoin: mitre post, oak, 11 inches × 10 inches: bottom bar, oak, 11 inches deep by 10 inches wide, rabbeted $3\frac{1}{2}$ inches on upper side, (*vide Fig.* 7,) connected with heel and mitre posts by L plates 3 inches × $\frac{1}{2}$-inch.

Filling in of fir beams, 10 inches thick, by any suitable width, bolted

together by 1½-inch round bar iron running through centre of thickness, at about 2 feet 2 inches apart from centre to centre of rods: ends fitted with nuts and washers. Fender planks of oak, 12 inches × 2 inches, spiked on to gates where boats are liable to rub, about 12 inches apart.

Balance beams, oak, 19 feet to 20 feet long. At mitre post, 10 inches by 10 inches: fall back, 10 feet 6 inches to cover heel post, where they are 12 inches to 13 inches square: at extreme end 18 inches to 20 inches square. If made too heavy at end, they are liable to wrench and twist gates, if not shut evenly.

Sluices, 19 inches × 14 inches clear width: one in each head gate 9¼ feet × 6⅓ feet:* the above area is found most suitable, larger area being liable to wet boats, and drag gravel into lock. Sluices of cast-iron, worked in oak frames and grooves, by iron rods, with ratchet and wheel. Sluices for side pond culverts are elm paddles working in oak frames and grooves, lifted by lever, and kept up by catch.

Gate pivots point *downwards*. Foreman preferred this arrangement, considering pivot less liable to break, and easier to be got at when attached to heel post. Cup in which pivot works cut like a slot O to allow of play. Sally of gates and mitre sill, 3 feet 6 inches for 14 feet lock.

Cost of a pair of tail gates for a 14 feet lock (height of a gate 12 feet 8 inches from top of mitre sill to under side of collar hole,) about £110 to £115. Cost of a pair of head gates, £90 to £95. Average cost say £100, of which amount labor averages about £10: used to average £12, but introduction of a planing machine reduced labor expenditure £2 per pair of gates. No lockmen maintained as a rule: where a flight of locks exists, one man paid as a sort of "caretaker," but all work at locks done by bargemen. As a set-off against this economy, must be put the extraordinary precautions everywhere noticeable against damage to locks from rough and careless handling of boats or lockgear.

Gauging Mill Streams.—All mill rights most tenaciously preserved laong line of canal, and gauging of mill streams invariably effected by flow over a notched board. Engineer said they preferred never having greater head than 6 inches on notch, extending length of crest as might be necessary.

Blisworth Tunnel.—1¼ miles long, width apparently 14 feet, (same as locks,) depth of water 5 feet; but here and there obstructions, (either deposits of gravel, or beams across bottom of tunnel,) reduce depth to 3.

feet 10 inches, or 4 feet. Only three ventilating shafts in whole length of arch crown, and one side shaft, opening out just above water surface. Formerly, boats were "legged" through the tunnels. Men, employed for the purpose, lay on their backs on boards, let down horizontally like wings from the boat's sides, and shoved boat through with their feet, pushing against sides of tunnel; on meeting another boat, wings had to be drawn in to admit of its passing. Charge for this cumbrous operation, 1*s.* for each empty boat, or laden boat under 20 tons; 15*d.* for each laden boat of higher tonnage. This system was re-placed last autumn by an endless rope of steel wire, which revolved round drums driven by steam power at one end. The rope was supported at the ends of tunnel, but inside was allowed to trail along the bottom, apparently owing to difficulty of getting the boat fastenings past the points of support. The boats were to make fast to the revolving rope, as they came up, and be towed through tunnel; but the ropes wore out so quickly that the Directors refused to continue the system, unless some firm would guarantee a rope to last for 18 months. At first none came forward, so tug steamers were ordered, and just as tugs were put on line, a firm volunteered to guarantee rope for the prescribed time. Tugs, however, are now worked in tunnel; although engineer preferred the rope, could he have got it to work satisfactorily. The Traffic Manager of Canal, however, considered objections to tug much exaggerated. These were—1*st*, Filling tunnel with smoke; 2*nd*, Causing greater expenditure of water in locks; 3*rd*, Delaying traffic.

Legging.

Towing rope.

Steam towing.

1*st.*—The smoke nuisance is said to be very great on foggy days, although the tug is fitted with a sort of smoke consuming apparatus. Tunnel was perfectly sweet and clear when I went through, on a bright clear day, but two men were actually suffocated in the tunnel on some previous occasion before smoke consuming apparatus was introduced.

2*nd.*—Expenditure of water, said to be increased by the fact of boats being towed through the tunnel in trains by the steamer. Formerly, by the "legging" and wire rope systems, boats worked independently, and when water was scarce, a boat arriving at head of a flight of locks, could without much inconvenience be kept waiting for a boat working up, so that the one working of locks would do for both. Now the towing through the tunnel in trains (boats being kept waiting until train is collected) tends to establish a system of trains up and down, which may

or may not meet at a flight of locks—most probably will not—so that a double expenditure of water is caused.

3rd.—The delay caused by tug is undoubted *at present.* Boats have often to lie at mouth of tunnel, waiting for the tug to return, or for other boats, quite an hour and a half, during which time they could have been "legged" through. Time is a much more important element in canal traffic in England than I had supposed. However, Traffic Manager says, that traffic will soon adapt itself to the new ways; that the steamer will have fixed hours for leaving either end of tunnel, which bargemen will soon learn and suit themselves to. Tug "Spider" working, when I went to tunnel, about 8 H. P. nominal, carries no cargo, draught about 3 feet 6 inches, can tow 13 boats, averaging 20 to 25 tons burthen each, over the tunnel reach ($1\frac{3}{4}$ miles) in $1\frac{1}{2}$ hours. Took us through without any train in 35 minutes, but steering at entrance of tunnel very wild, owing to darkness of tunnel and tug's tendency to run about. The banging against sides of tunnel was most reckless, bricks knocked out of masonry lining by shocks of barges, &c., in many places. Tug, when going through a narrow channel, drives water ahead of it (quite one foot difference of level between water surface a few yards ahead of tug and opposite screw when we were going through). This of course impedes way of boat, and makes it settle down very much astern, increasing apparently the draught. Towing a boat keeps stern up somewhat, but still *ample depth must be allowed in all contracted channels below keel of deepest boat likely to pass.*

Tug "Spider."

Dredges.—Two small dredges, each about 8 H. P. nominal, steadily employed in removing sand and gravel from bed of canal. Work at a cost of about 6*d.* a ton dredged; one will load a 30-ton boat in half an hour. A hand dredger also used, consisting of a scoop at end of a long pole lifted when full by a rope and windlass in bows of boats; four men can lift into boat and empty 20 tons of mud (one boat load) in a day; contract rate 1*s.* per ton dredged and emptied.

Boats.—The boats in use on canal vary from 15 to 35 tons burthen, beam about $\frac{1}{10}$th length; draught never exceeds 3 feet 6 inches.

35 ton cargo boat, 71 feet long, 7 feet 1 inch wide at water line,* 6 feet 6 inches at bottom, 3 feet 10 inches depth of side in centre, shearing up 12 inches to each end; draught when fully laden $3\frac{1}{2}$ feet, cost £135 to £145.

* A little less at gunwale

Hauling.—I saw some boats being towed from the gunwale by a rope passed under thwart A, made fast at centre B of boat's length, (*vide Fig.* 8). Others from a mast placed at about one-third boat's length from bows and standing about 6 feet above water surface. The boatmen prefer the latter method as the pull is more direct: tendency of it is to keep bows of boat down in water (instead of lifting them out as when towing from gunwale) which makes boat steer better; and, thirdly, rope clears all obstacles on towing-path. The further aft the point of attachment is, the easier the boat will steer, provided it does not pass midships. In towing barges by tug, towing rope is attached to swivel in stern of tug, owing to want of space on deck of tug; but it should in preference be attached to a ring running on a bridge about 10 feet from stern, and the nearer midships the point of attachment is the steadier tug will be.

Steam Towing.—Towing by steam evidently does not pay where there are many locks, but in long level reaches its cost is just about half that of towing by horse-power. Speed of horse never exceeds 2 miles per hour; tugs do $2\frac{1}{2}$ to $3\frac{1}{2}$ miles an hour without distressing anything. Traffic Manager of Canal considered that steam haulage paid when 25-ton steamer, 8 H. P. engines, carrying 15 tons cargo herself, towed boats carrying altogether 60 to 65 tons more cargo, from London to Birmingham, a distance of 150 miles (136 locks). Estimated average cost of steam haulage on canal, 0·38*d.* per ton per mile, including all expenses. Where haulage by horses is still used, the Company provides horses in relays at every 20 miles, barge owners paying for their use. Notice sent by post to men in charge of horses at various main stations of despatch of trains from either terminus, stating number of horses required.

At first the canal was only used by traders and Carrying Companies, but as railways became generally used for traffic, the Canal Company found that they would lose all their custom, unless they became carriers themselves, and they now engage to collect and deliver goods just as any Railway Company does. Great efforts are made to retain custom during seasons when canal is closed by frost, (as it was for five weeks of the winter just past,) it being found that when men get "a taste of the rail" they are hard to lure back to the canal.

March 11*th*, 1871. H. A. B.

No. CLXVII.

REPORT ON AMSTERDAM SHIP CANAL.

By Lieut. J. F. Miller, *Assoc. Inst. C.E., Exec. Engineer, Punjab Irrigation Branch.*

General Description.—The object of this canal is to provide a shorter communication between the great Shipping Port of Amsterdam and the North Sea than that at present existing by the North Holland Canal.

The new canal, commencing at Amsterdam, passes through the Lakes Ij and Wijker Meer, strikes the elevated ground of the Western "dhunes" or Sand Hills, near Velsen, and is carried in considerable cutting through them, during the last three miles of its course, till it reaches the sea, where its mouth is protected by two long breakwaters of about a mile in length, their ends being slightly inclined to each other. These breakwaters enclose a harbour of about 750 acres, well sheltered against storms from all sides. At about half a mile from the sea are the locks, three in number, and abreast of each other. Two of these are arranged for the passage of shipping; and the third, on the right flank, for sluicing. The total length of the canal is 15 miles, thus saving a distance of 35 miles over the distance traversed by ships at present using the North Holland Canal, which latter is 50 miles from the Helder to Amsterdam.

The dimensions of the new canal are as follows:—

	feet.
Width at water's surface, ...	197
Do. bed of canal, ...	88
Depth of water in do., ...	23
Berms on either side, each, ...	33·3
Width of locks, ...	60

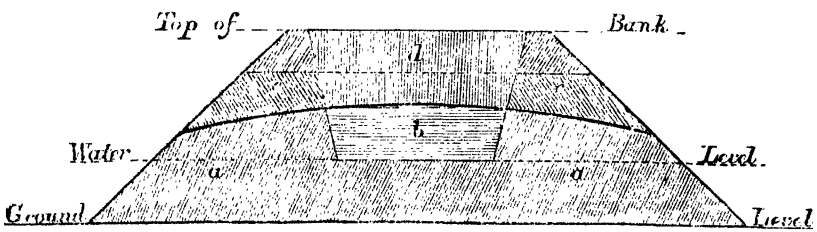
The berms are about 1·5′ under water, and spoil banks 15·5′ wide at top.

The canal is being excavated by an English Company, under concession from the Netherlands Government. A large portion of the stock being held by Dutch capitalists, some of whom are also Members of the Board of Direction, and from their local knowledge well able to offer wise counsel. The original estimate for the Project was two millions sterling, and the Company decided to carry out the work by contract, arrangements being entered into with the English firm of Henry Lee and Co., who commenced operations some eight years ago, and will, in all likelihood, complete the canal within the stipulated period of 10 years. A close supervision of the works is maintained by the Dutch Government, by whose Engineers all works have to be passed on completion, and who indicate generally the conditions under which operations shall be carried out, both as to the building of the canal and its working.

In connection with the canal, and simultaneously being executed, is a system of reclamation of lands hitherto under water, to the extent of 13,000 acres, divided into eight plots termed "polders," and occupying the whole of the surface known as the Lakes Wijker Meer and the Ij. Up to the present time the whole of the former lake has been drained, and a portion of the latter, and crops grown thereon. The out-turn from such lands being extremely good, and fully justifying the belief that this part of the scheme must prove financially a success. Indeed, the feasibility of reclaiming large shallow lakes has been so far established as to render it probable that ere long operations will be initiated for dealing in the same manner with the whole Zuyder Zee. The main objection to the more extended scheme being that it would interfere considerably with the privilege of water carriage, at present enjoyed by towns on the shores of this inland sea. The inhabitants would either have to be heavily compensated for the loss of such accommodation, or else provided with a system of canal communication by branch channels to enable their shipping to reach the main trade arteries. The money provision for this great undertaking has been stated at as high a figure as 40 millions sterling, but this was under the supposition that the old expensive system of embanking in vogue in Holland would be resorted to; whereas, Mr. Lindsay (the Contractor's Engineer for the Ship Canal) believes that the object might be attained for an expenditure of only four millions sterling; his plan of forming embankments being adopted. In much of the land reclaimed a stratum of peat turf has been found, the removal

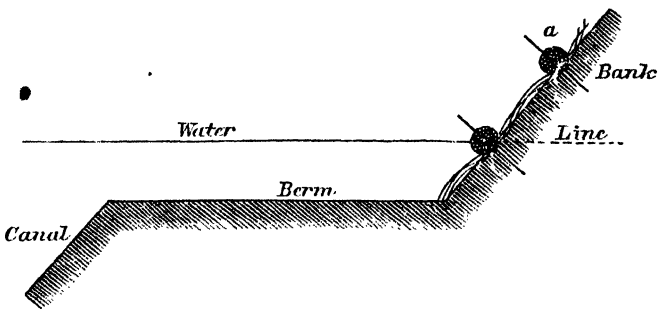
of which, previous to the commencement of tillage, provides a supply of a valuable saleable commodity.

Excavation of channel.—Throughout the portion of the canal extending from the Zuyder Zee at Amsterdam to the deep cutting, commencing at Velsen, where the line passed through shallow lakes, the section was dredged out, and the material deposited on the sides to form banks. But this material not being found sufficient for the purpose, the earth from the deep cutting was brought in barges and placed on the top of the banks formed by the dredgers. This process was found, however, to be very expensive, and was consequently discontinued in favor of a plan invented by Mr. Lindsay, which is conducted as follows: the cost of forming banks by this means being to that of performing the same work by carriage of earth in barges as 1·5 : 20.



The bank *a* having first been formed with dredged material, deposited from shoots in connection with the dredging machine, to a height slightly above the water level; two small dowels *c c* are formed by hand, of earth excavated from trench *b*." The space between these dowels is then filled up by pumping liquid mud on to it, the water of the mud flowing away through a trough in the dowel, and the solid particles depositing in thin compact layers. If sufficient height has not been obtained by filling up to the top of the dowels first constructed, a second and similar operation would be conducted to raise the embankment to any height necessary. The pump used for this is of the ordinary centrifugal type, and has a scarifying wheel with pronged arms, working opposite the mouth of its uptake pipe. This stirs up the mud at the bottom and ensures a supply of ooze, often containing as much as 70 per cent. of solid matter in suspension. The pipes which deliver this mud on to the embankment are about 18-inch bore, and in 10 feet lengths, joints between them being made by leather sleeves, secured on the end of each

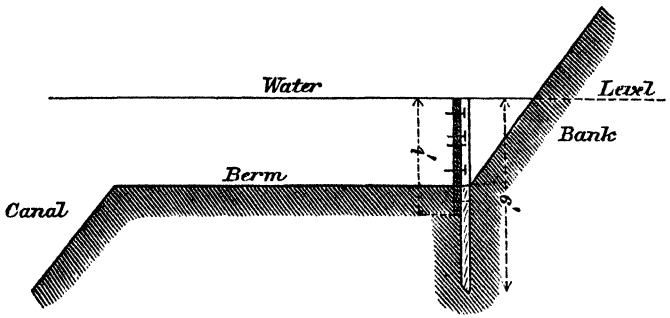
pipe by means of a hoop-iron band. The pipes are of pine lathes, built together, and hooped like the staves of a cask. The pumps and engine actuating them are in a barge, which moves along the canal to any point required. The pipes are then laid out from the delivery port of the pumps to the embankment, being floated on the intervening water by the attachment of timber balks. The banks of the canal in this, the shallow cutting, are protected from wash of passing steamers by a covering of wattles laid as shown below.



Three layers of wattles interlace under the lower fascine, the top of the upper layer being confined by the fascine *a*. The fascines are pegged through with stakes driven well into the slope.

The part of the canal extending from Velsen to the Harbour Works on the North Sea, and passing through the Sand Hills is in many places in very deep cutting. Its construction was carried out by locomotives drawing trains of the excavated material up inclines of various gradients, from 1 in 70 to 1 in 100, the stuff being either deposited in spoil or run out on a staging over a portion of the canal already in use, and tipped into barges which conveyed it to points where the banks needed raising in the lake portions of the canal. There were 11 locomotives employed in all on this three miles of channel, and the day's work averaged 20 sets of 20 to 24 two and-a-half cubic yard wagons run out of the cutting. The inclines were arranged on either bank of the canal, and such of the material as lay in a position behind the lower terminations of the incline was 'back-handed.' The weight of the empty wagons was 1·5 tons, and their duty per mensem for each one employed, 35,000 cubic feet.

The protection of the banks in the deep cutting is effected with oak piles and pine planking disposed as below.



Oak piles at 4 feet intervals, with 2 inch planks (of which there are four, each 1 foot deep) spiked to them.

Locks.—The locks are of brickwork with sandstone quoins, sills, &c., and have double gates for safety, the outer being of strongly framed iron-work, and the inner of wood. Excepting their great size (150′ × 59′) there is nothing peculiar about these works. The provision of a separate lock channel for sluicing, and that one on the flank, is open to question, as it only performs a function which the central chamber could equally have performed, and from its position induces a scour down one of the canal banks, where eroding action is not desirable.

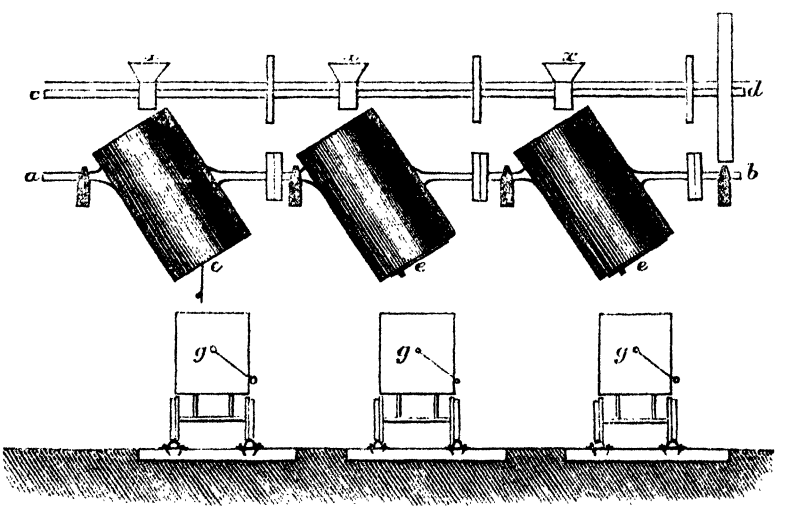
The getting in of the foundations of the locks was attended with much difficulty, owing to the unstable nature of the substratum. A coffer-dam having been constructed, preparations were made to lay in a concrete foundation, but before this could be done, the pressure of the water-logged sand so affected the sheet-piles of the dam that their feet were pressed inwards till they met, their cross section resembling the letter V. Mr. Hawkshaw, who was employed as Consulting Engineer, determined to lay in the foundations between the piles as they were, and not to re-construct the coffer-dam, and this was done with good effect, no subsequent settlement having taken place.

Break-waters.—The two long moles which run out into the sea at the mouth of the canal are constructed of concrete blocks, weighing from 10 to 20 tons each, laid in position by a Wellington Crane. The rock at the bottom is roughly levelled by divers previously to laying in the lower blocks, and all the blocks are cramped together with iron. The

upper courses above water-level have their joints grouted up with Portland cement, and the top of the completed work is also finished off with a plaster of the same. The Harbour works are connected by rail with the concrete factory, on the canal bank at Velsen. The plant for the manufacture of blocks having been erected there as soon as the canal had been completed to that point, thus securing water-carriage for the materials so far.

Hitherto the break-waters have stood well the storms of winter, and where failure of any part has occurred, the cause is assigned to the lightness of the blocks first used (10 tons), and arrangements are being made to re-place them by blocks of double the original weight.

Factory for Concrete Block.—This is established at Velsen—the point where the deep cutting commences—the yard being close to the bank of the canal. All material is brought here in barges, and unloaded by four steam cranes, erected on stagings over the boats. The cranes deliver the shingle, &c., into wagons, drawn by horses on trams, to the mixing cylinders, whose hoppers are placed on a staging about 20 feet high, and provided with a steam crane, by which cement, &c., are raised and tipped direct into the hoppers.



The above sketch shows the arrangement of the three mixing cylinders fitted on the counter-shafts *a* to *b* to which latter motion is given by a belt from the main shaft *c*, *d*. Each counter-shaft is provided with fast and loose pulleys, so that the cylinders can be stopped and started sepa-

rately. The following charge is filled into the mixing cylinder at each feed, and represents the composition of the concrete blocks as used:—

Shingle,	½	c metre.
Sand,	3	do.
Portland cement,	1	do.
Water,	6	buckets.

This having been run into the revolving cylinder, through the hopper on platform *x*, and mixed for about five minutes, by rapid revolution of the cylinder, is shot through an opening in the bottom into an iron skip *g*, standing on a line of rails below, and is drawn away by a horse till it comes under a travelling gantry, which spans the triple track of rails shown. Then the skip is lifted off the platform lorry by a winch on the gantry, and its contents tipped into the moulds—standing outside the rail track, after which it returns empty for another charge. A 24 horse-power low pressure horizontal engine gives motion to the three mixing cylinders and to a long square shaft, extending down the supports of the elevated gantry road. This shaft has a bevil wheel sliding freely on it by which motion is communicated to the winch on the gantry, for lifting boxes to tip into the moulds, and finished blocks out of the moulds, when sufficiently set for removal. The blocks are made in moulds arranged in sets of ten, (*Fig.* 1,) thus making each plank side (not an outer one) do duty for two moulds, as below; the outer planks (shown double) are the only moveable parts—the remaining divisions being dove-tailed into the floor. The thickness of plank used is 2½ inches. *Fig.* 2 shows how the

Fig. 1.

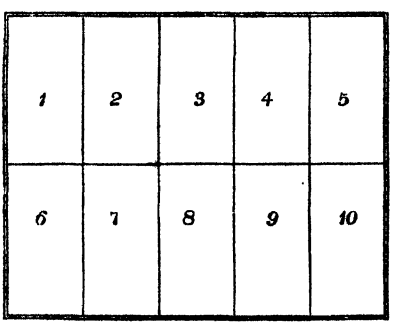


Fig. 2.

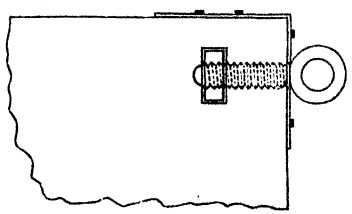
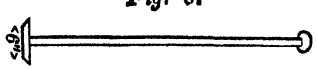


Fig. 3.



eye-bolts to hold up the sides are attached, by screwing their ends through

a nut sunk in a slot cut in the thickness of the plank. Templates of wood are built into the moulds with the concrete, and being afterwards withdrawn, leave apertures for the insertion of the cramps used in securing blocks to each other in the work, and for fixing the lewis by which the blocks are lifted out of the moulds. The lewises are of the form shown, (*Fig.* 3,) two of them being employed to raise a 10 ton block.

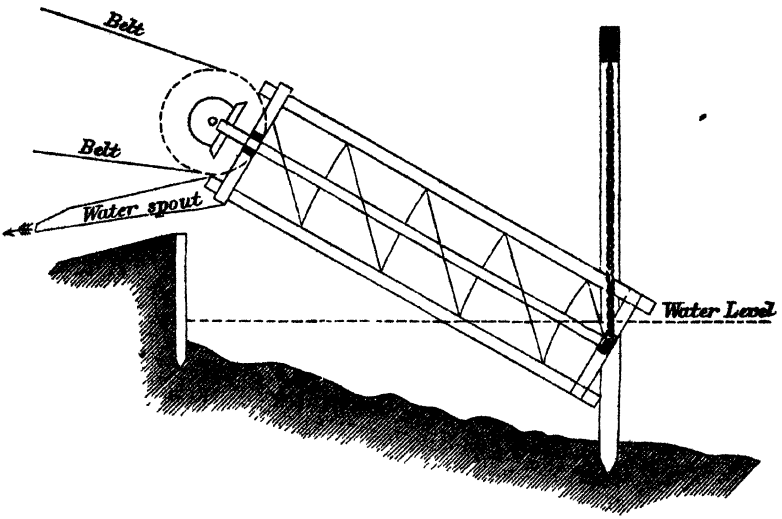
With the three mixing machines in full work, the out-turn varies from 40 to 50 blocks per diem of 14·5 working hours, by piece work. The blocks remain seven days in the moulds. They are then stacked in the air for three months previous to use.

Reclamation of Swamps.—The reclamation of water-covered lands is carried on simultaneously with the completion of the canal channel, for the banks of the latter serve to protect the tracts to be drained, while the canal itself conveys away the water pumped off.

The first operation after the swamps has been dammed all round, is to dredge a large central drain, its bed sloping towards the canal, and having its outfall in the well of the pump which raises the water. At right angles to this channel and delivering into it, a number of V shaped trenches are cut at intervals of about 100 feet, the excavated stuff being placed on the spaces between them. These are dug after the water has been sufficiently drained off by the main channel to allow of laborers landing on the swamps. Incessant pumping is then carried on till the whole tract is drained to a depth some two feet below surface, when a crop of oil seed is sown. The digging of the minor drainage channels costs 1 franc per c. mètre.

The pumps used at first to drain the lakes are of the Archimedian screw type. Some of them having a diameter of 3·12 metres over the screw blade. The pitch of the screw is made equal to its diameter, and the larger ones have three threads. Both core of screw and blades are of wood, the latter let into a groove cut on the centre post and their outer edges connected with hoop iron. The accompanying sketch shows how these wheels are mounted, the lower framing, in which the shafts of the screw works, being fitted with an iron gudgeon, is slung from a frame above by a chain, and the pump can thus be adjusted to accord with the water's level as it falls. With a view to equalise the quantity of water taken by the screw at different positions as regards verticality, the spiral of some of the screws has been made to taper towards its lower end. But this

appears to be a nicety of construction not productive of advantages commensurate with the extra trouble in building.



The top of the screw carries a bevil-wheel in gear with another on a horizontal shaft, driven by a belt direct from the engine. Thus, whatever angle the screw may be at, these wheels are always in gear.

The cost of raising water to a height of 10 feet by means of these pumps was 2 francs per 1000 c. mètres.

As soon as the water has been sufficiently got under to allow of the foundations being got in, an engine house is built in each tract of reclaimed land, and engines and pumps fitted up for permanent use. The pumps are of the centrifugal class, driven by gearing direct off high-pressure engines.

Miscellanea.—All crossings, both road and railway, over the Amsterdam Ship Canal are provided with swing bridges. Road Bridges remain closed to the canal except for passage of boats, and railway bridges closed to the railway exceptfor trains to cross. The traffic on the railways is small, so this system is not productive of inconvenience.

All boilers employed on the canal works are fitted with injectors in place of the ordinary feed pumps. These appliances are also used to pump out the dredger barge bilges.

J. F. M.

No. CLXVIII.

STONEY'S DOUBLE-ACTING HELICAL EXCAVATOR.

[*Vide* Plates XXXIX., XL. and XLI.]

By E. W. Stoney, Esq., B.C.E.

When sinking the cylinders of the new Cheyair Bridge, Madras Railway, it was found that "Bull's Dredge," which excavated sand in the most satisfactory manner, was powerless to excavate clay, kunker, and other similar stiff material met with.

Many of the cylinders had to be sunk through twenty to forty feet of stiff clay, underlying thirty feet of sand, so that it became necessary to get some efficient apparatus to excavate this clay under water, it having been found impossible to pump the cylinders dry. Under these circumstances the Author, who had charge of the works, after some experiments, designed the Excavator shown in *Plates* XXXIX. and XL., and in *Fig.* 1, *Plate* XLI.: and subsequently, the more simple form shown in *Figs.* 4, 5, 6, 7, *Plate* XLI.

Description of Excavator.—This Excavator consists of a wrought-iron body, of the form shown in *Plates* XXXIX. and XL., and *Fig.* 1, *Plate* XLI., from the bottom of which triangular portions are cut away at opposite side of the centre, the edges EE being so bent down, and sharpened, as to form "Helical Cutters."

In the sides of the body B, openings are left which correspond in positions with those in the bottom, the edges CC of these being also sharpened to act as cutters.

Turning freely within the body is a false bottom F (colored purple), with sides, the whole being of such size and shape as to cover the openings in the bottom and sides of the body B, so that an open or closed vessel may be formed at will, by merely turning the false bottom F into the positions shown in *Figs.* 1, 2, *Plate* XXXIX.: and *Fig.* 1, *Plate* XLI., and *Fig.* 1, *Plate* XL., respectively.

To the false bottom F is riveted a bar K, having secured to its centre,

DOUBLE ACTING HELICAL EXCAVATOR

FIG. 2
ELEVATION WHEN OPEN.

above and below, circular plates *a*, *b*, in which are square holes of sufficient size to allow the rod R to run freely.

The lower circular plate *b*, above described, turns freely in a corresponding hole in the bottom, and bar *t* attached thereto to strengthen it (*vide Figs.* 2, and 7, *Plate* XLI.); whilst the upper plate *a* turns in a circular hole in the guide bar L, which is bolted to the body B.

It will be observed that the false bottom F is thus left free to move through a portion of a circle, the extent of such motion being limited by angle iron stops V, V.

The Excavator is suspended by three wrought-iron chains, the upper and lower extremities of which are attached respectively to a shackle S, and eye-straps H, H, riveted to the body B.

The rope O, by which the whole machine is raised and lowered, is tied to the swivel T of the shackle S.

A modification of the form shown in *Plates* XXXIX. and XL., and *Fig.* 1, *Plate* XLI.; is illustrated by *Figs.* 2, 3, *Plate.* XLI.: in this only two stops V, V, are used, and the openings are larger than those in the former *Figs.* This form is most effective in very stiff clay, and is the best shape for small sizes under 2 feet 6 inches in diameter—it will probably be found the shape most generally useful.

Another form of Excavator shown in *Figs.* 4, 5, 6, 7, *Plate* XLI., consists of a circular wrought-iron body B, without side openings, the bottom having two openings formed in it, the edges EE of which are bent down and sharpened to form Helical Cutters. Cutters C, C, are also formed on the sides.

Within the body B is placed a false bottom F (colored purple), without sides, of size sufficient to close the orifices in the bottom, arranged so that it may be turned to leave these orifices either open or shut, so as to form at will an open or closed vessel, as shown in *Figs.* 4 and 5, respectively.

The false bottom F is turned by a bar K, riveted thereto, which has circular plates *a*, *b*, with square holes in them attached to it; these plates turn in corresponding holes in the bottom of the Excavator, and guide L fixed to the same; the extent of the motion of the bottom F being limited by angle iron stops V, V, placed as shown in *Figs.* 4, 5, *Plate* XLI., against which the bow K bears. The bottom is strengthened by a bar *t* under it.

This form possesses great strength, and is so simple that it cannot easily be deranged in work. It is the best shape for large sizes, from 3 feet to 6 feet in diameter. The size may be regulated to suit that of

the well or cylinder to be excavated, as in consequence of its being circular, and smooth on the outside, it may be made nearly equal in diameter to the well in which it is to be used, so that the whole area of the interior may thus be evenly excavated at once.

The advantages arising from this will be readily appreciated by those who have had to sink wells through hard materials.

The form of Excavator shown in *Plate* XXXIX. and XL., and *Fig.* 1, *Plate* XLI.; has been found that best suited to small sizes for working in stiff clay, or silt, while for large sizes those of the shape illustrated in *Figs.* 4 to 7, *Plate* XLI., are best.

When working in silt, angle-iron or steel cutters affixed to the bottom of the small Excavators were found most useful, as they disintegrated the material for the Excavator to take up. These cutters may also be used with advantage in kunker, which may be broken up by first using the Excavator percussively as a jumper.

Modes of using the Excavator.—The mode of using the Excavator is as follows:—A derrick pole is set up so that its head may come over the cylinder to be sunk, and by means of it and suitable tackle, the rod R, of such length as is necessary, is placed in the cylinder, with its bottom resting on the material to be excavated, and its top some ten feet over the cylinder top.

Pulley blocks M, *p*, *Plate* XL., and *Fig.* 10, *Plate* XLI., are placed near the top and bottom of the derrick, through which a 5-inch Manilla rope is rove, one end of which is fastened to the Excavator shackel S, *Plate* XL., while the other end O is carried to a crab winch.

The Excavator is now placed on the rod R, opened, and allowed to run down along the rod till it rests on the material to be excavated, at the bottom of the cylinder, as shown in *Figs.* 1 and 2, *Plate* XXXIX.

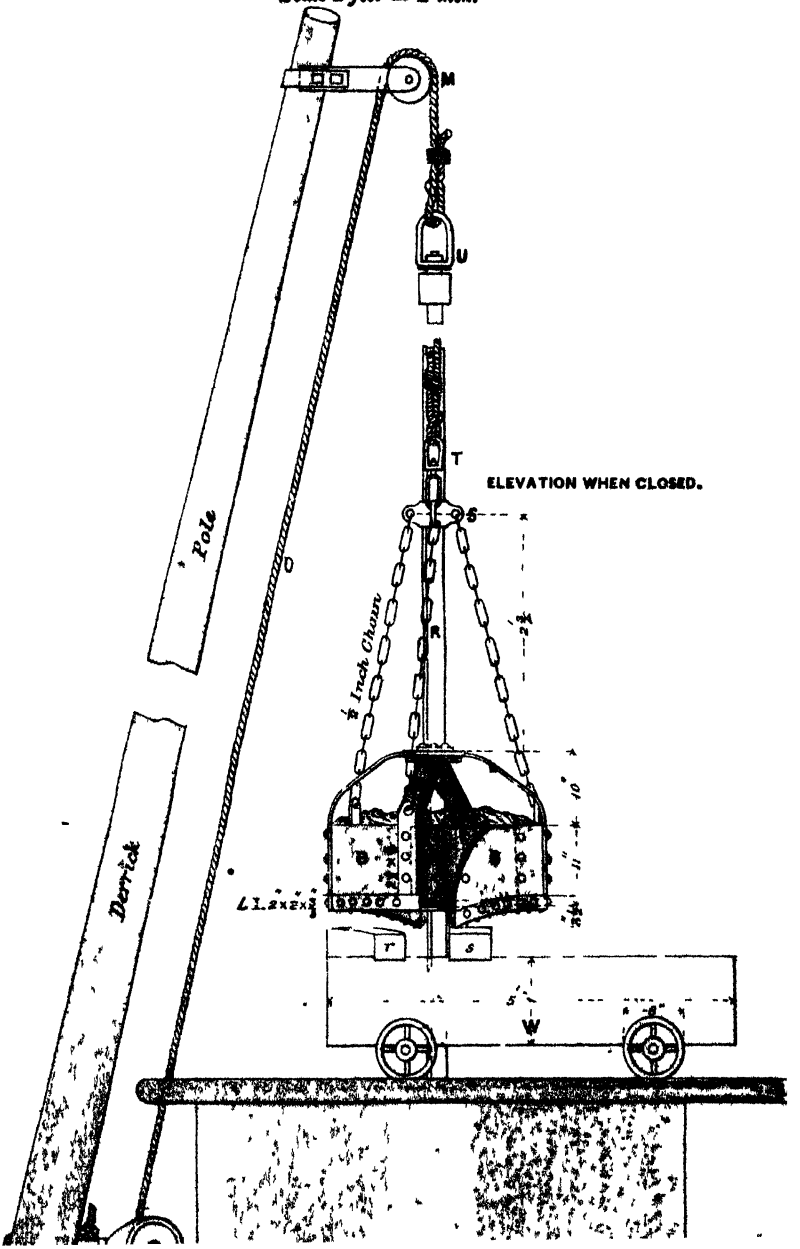
The guide piece D is then placed as shown in *Figs.* 1 and 3, *Plate* XXXIX., and the handle X having been put on, the rod is turned four to six times round in the direction in which the hands of a watch move, which fills the Excavator; the handle is then turned in the opposite direction till the false bottom F comes into the position shown in *Fig.* 1, *Plate* XLI., and *Plate* XL., which thus closes the Excavator.

When working in stiff clay, the Excavator handle requires a few smart jerks back and forward to close the Excavator, as a steady push cannot cut through the clay it holds

After the Excavator has been closed, it is raised by means of the rope

STONEY'S DOUBLE ACTING HELICAL EXCAVATOR.

Scale 2 feet = 1 inch.



O and crab winch, till near thetop of the cylinder; when the guuide D and handle X are removed, and the raising continued to a sufficient height to allow of the barrow W being run under the Excavator, which is lowered thereon, opened, and its contents discharged therein (*vide Fig.* 1, *Plate* XLI., and *Plate* XL.).

As soon as the Excavator has been emptied, it is raised clear of the barrow, which is then run into the position shown in *Figs.* 1 and 3, *Plate* XXXIX., and its contents thrown out over the side of the cylinder, and while this is being done, the Excavator is being lowered ready for the operation just described being repeated.

The different forms of Excavator illustrated are worked in a precisely similar manner. It is not necessary to use a barrow, but it has been found convenient to do so when working with a length of rod over the top of the cylinder.

When it is found desirable to work with a short length of rod, or when the top of the rod sinks below the cylinder top, the use of the barrow may be dispensed with, and the Excavator raised off the rod each time, and discharged over the side of the cylinder in which it is being used.

A small flap valve *w*, *Figs.* 2 and 7, *Plate* XLI., of iron, falling by its own weight, closes the square hole in the bottom of the excavator as soon as it is raised off the rod, and thus prevents the escape of excavated material from it.

When a derrick and crab winch cannot be placed on the river bed, they may be placed on suitable staging, fixed on the well top or on temporary piles, so that the Excavator may be worked in each particular case in the most advantageous manner.

Size and capacity of Excavators.—The sizes of Excavators used at the Cheyair Bridge, with their weights, capacity, &c., are given in the annexed Table:—

Table of Excavators used at Cheyair bridge.

Description of Excavator	Diameter of Excavator		Height of Excvtr.	Cubic contents inside	Weight in lbs.		Remarks
	feet	inches	inches	cub feet	Empty	Full of Clay	
These are of the forms shown in *Plate* XXXIX and XL.	1	8	10	1·81	200	417	The weights given are the average results of experiments.
	2	3	12	3·97	252	728	
	2	6	11	4·50	336	876	
These are of the forms shown in *Figs.* 4 to 7, *Plate* XLI.	3	..	9	5·29	364	999	
	4	..	6	6·28	440	1194	

size which would keep straight, and sufficient to resist the torsion to which they were subject. Rods of various lengths, from 40 to 80 feet all in one, were used, made up of 12 foot bars welded together.

No difficulty was experienced in getting rods up to 60 feet in length raised with the derricks, and putting them into the cylinders, but when they exceeded this length they became troublesome to handle.

The Author has, however, recently designed a joint of steel, (of which *Figs.* 8 and 9, *Plate* XLI., are illustrations of the bottom and underneath rod joints,) which does away with inconvenience arising from the use of long continuous rods; and jointed rods may now be made in such lengths as may be found best suited to the excavations in hand.

It will in general be found convenient to use a rod consisting of a bottom length 15 to 20 feet long of $2\frac{1}{2}$ inches square iron, with intermediate pieces 30 feet long of 2 inches square iron enlarged at the joints to $2\frac{1}{2}$ inches square; as shown in *Figs.* 8 and 9, *Plate* XLI.; some short lengths of 10 feet or so being provided as adjusting pieces to keep the top of the rod at a convenient level over the cylinder top.

These joints, though somewhat troublesome to make singly by forging and fitting, can be produced readily, if required in numbers, of crucible cast steel.

When a rod exceeds 40 feet in length it should be suspended by a swivel, as shown in *Plate* XL., and *Fig.* 5, *Plate* XXXIX., as by doing so it is relieved from the bending stress thrown on it by its own weight which now keeps it straight, and so allows the Excavator to run freely up and down it.

It has not been found necessary to suspend continous rods 40 feet or under in length, though when they are jointed it is desirable to do so, in order to relieve the joints from bending strain.

Swivel.—The construction of the swivel is shown clearly in *Plate* XL., and *Fig.* 5, *Plate* XXXIX.—it is secured to the Excavator rod by a taper pin, which fits so that it may be readily knocked in or out.

The rope O attached to the swivel U (which may have a swivel in it to allow of its turning more freely) is passed through the sheave M of the triangular double block, *Fig.* 10, *Plate* XLI., and then tied to the base of the derrick or crab.

The Excavator Rod can be raised and lowered, and its position changed when desired, by passing this rope round the crab winch barrel.

By the use of a triangular block, such as is shown in *Fig.* 10, *Plate* XLI., the rope by which the swivel and rod R is suspended is kept

apart from that attached to the Excavator, and so kept from getting in twist with it.

Excavator handle.—A very simple and efficient handle for working the Excavator, designed by the Author, is shown in *Figs.* 3 and 4, *Plate* XXXIX. It is made so that it grips tightly the rod R, and can be rapidly put on or taken off.

Its construction is clearly shown by the elevation and horizontal section in the *Figs.* quoted, and it is used in the following manner:—

To put it on, turn up the catch Q, as in *Fig.* 3, so as to allow the handle to be slipped on the rod R, then turn the catch Q down till it rests on the stud bolt *d*, of which P is the nut, and turn this nut by means of its handle, so that it may squeeze the catch Q tightly against it.

The handle can be taken off by unscrewing the nut P, and lifting the catch Q.

The whole operation of putting on and taking off the handle can be thus effected in a few seconds.

It will be seen that the handle possesses several advantages over the forms ordinarily used, which will be appreciated by those who have had to use them.

1*st.* It is self-contained.

2*nd.* There are no loose parts which can be lost like the nuts or stud bolts of ordinary handles.

3*rd.* It requires no key, pin, or wrench (liable to be lost or mislaid), to screw it up.

Barrows.—The construction of the barrow W is simple, and is clearly shown in *Figs.* 1, 3, *Plate* XXXIX.; *Fig.* 1, *Plate* XLI.; and in *Plate* XL.

February, 1875. E. W. S.

Working drawings, with directions for making these Excavators, as also full information about them, will be supplied by the Inventor to any person desiring to make and use them.

The Royalty should be paid to Messrs. Arbuthnot & Co., Bankers, Madras, the Inventor's Agents by whom receipts will be given for such payments.

Letters of enquiry may be addressed to W. Stoney, C.E, Madras Railway, Chief Engineer's Office, Madras.

No. CLXIX.

CIVIL BUILDINGS—AMRITSAR.

[*Vide* Plates XLII., XLIII., XLIV.]

Designed and commenced by J. GORDON, ESQ., C.E., *and completed by* RAI KUNHYA LAL, *Assoc. Inst. C.E., Exec. Engineer, Lahore Division.*

Note by W. Purdon Esq., C.E., Supdg. Engineer, 3rd Circle, Punjab.

THE design for these buildings was made by Mr. John Gordon, C.E., Exec. Engineer, the foundations and a portion of the superstructure were completed when I assumed charge of the 3rd Circle of Superintendency, which included Amritsar. Messrs. Harington, Smithe, and Lyons, were all for a short time in charge of the Station, and some portion of the buildings were erected under their charge, but Rai Kunhya Lál, Exec. Engineer, carried out by far the greater portion.

The style of architecture appear to me to be scarcely well suited to this climate, as it affords so little shade, while the solid character of the verandahs tends rather to retain the heat, nor can the cornices and ornamental portions of this style of architecture be satisfactorily carried out in brick masonry.

W. P.

The Civil Buildings at Amritsar, represented in the accompanying Plates were designed and commenced by Mr. J. Gordon, Exec. Engineer,

and carried on vigorously by Messrs. Harington, Smythe, and Lyons, and completed by me in November last.

They contain the following accommodation:—

	Length.	Breadth.
Town-hall, ...	79′ 10″	× 28′ 3″
Museum, ...	42′ 5″	× 28′ 3″
Small Cause Court, ...	56′ 6″	× 42′ 5″
City Magistrates' Court, ...	33′ 10″	× 28′ 3″
Police Office, ...	33′ 10″	× 28′ 3″
Municipal Office, ...	33′ 10″	× 28′ 3″

Two wings for city police, with lock-up, each wing measuring 103½′ × 62′ outside.

The style of architecture is "Italian," and the buildings are constructed as follows:—

The masonry throughout is of the best burnt bricks, laid in good lime mortar; the outside being *fine dressed*, and the inside pucka plastered.

Floor of town-hall is of red sandstone, and the rest of the building has pucka tile floor.

The doors are of well seasoned deodar wood, made of neat pattern; those of the town-hall being fitted with stained glass.

The main rooms have a slate roof, supported on neat and strong deodar wood trusses, and the rooms in the wings have flat terrace roofs on deodar beams, kurrees, and bricks. The verandahs all round are arched without any tie-rods.

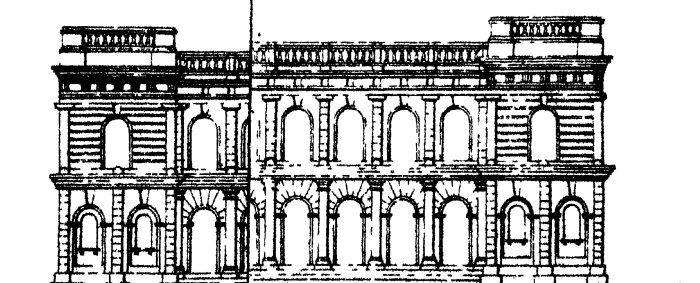
The upper glazed windows of the building are fitted with venetians outside, to keep out heat and rain, &c.

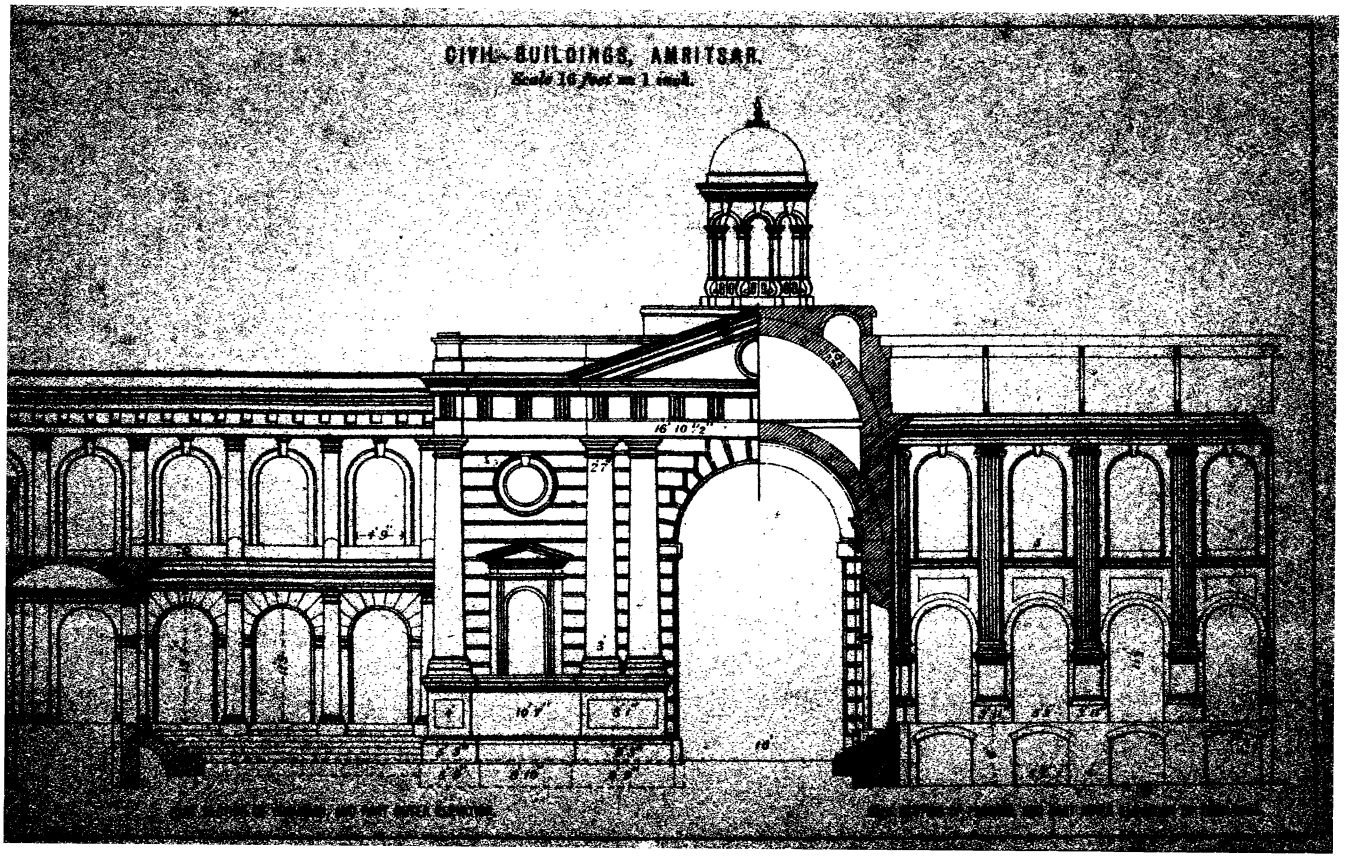
The main entrance to the building is through the central passage, which is surmounted with ornamental turrets of fine brickwork at each end.

The drainage from the roof is carried through pipes inside the walls, which empty themselves into large drains at the foot of the steps on both sides of the central passage.

The space round the building is metalled with kunkur and sloped outwards, so as to lead all rain water away from the buildings.

The total cost of the buildings is Rs. 1,72,034, details of which, showing the quantities of work, and the actual working rates, are given in the annexed Abstract.




CIVIL BUILDINGS, AMRITSAR.
Scale 16 feet = 1 inch.

Abstract of Cost of Civil Buildings at Amritsar.

c. ft.		Rs.	A.	P.
61,630	Pucka masonry in foundation of buildings, 39,454, at Rs. 18 per 100, ... Pucka masonry in plinth of buildings, 22,174, at Rs. 18 per 100, ...	11,093	0	0
12,826	Extra work in foundation, at Rs. 18 per 100, ...	2,218	0	0
2,24,790	Masonry in plinth of facade, dressed, 23,159, at Rs 33, per 100, „ superstructure, 2,01,631, at Rs. 33, per 100, ..	74,181	0	0
s. ft.				
21,990	Arched roofing, at Rs. 48 per 100, ...	10,555	0	0
c. ft.				
95,433	Earthwork under floor, at Rs. 6 per 1000, ...	573	0	0
s. ft.				
774	Flat roofing under 12 ft. span, complete, at Rs. 34 per 100,	263	0	0

Details of above Roof.

78' 6"	c. ft. deodar wall plates and Burgahs, at Rs. 15 per foot, ...	Rs.	73
82 6"	c. ft. deodar beams, at Rs. 1-10 per foot, ..	„	134
774	s. ft. roof covering, at Rs. 7-2, per 100, ..	„	55
		„	262
s. ft.			
8,594	Flat roofing under 20 ft. span complete, at Rs. 49 per 100,	4,211	0	0

Details of above Roof.

1502' 11"	c ft. deodar beams, at Rs. 1-10 per foot,	Rs.	2,442
123' 7"	c. ft. kurrees and wall plates, at Rs. 15,	„	1,154
8594	s. ft. roof covering, at Rs. 7-2, per 100, ..	„	613
		„	4,209
s ft.			
13,332	Trussed roof, complete, at Rs. 100 per 100, ...	13,332	0	0

Details of above trussed Roof.

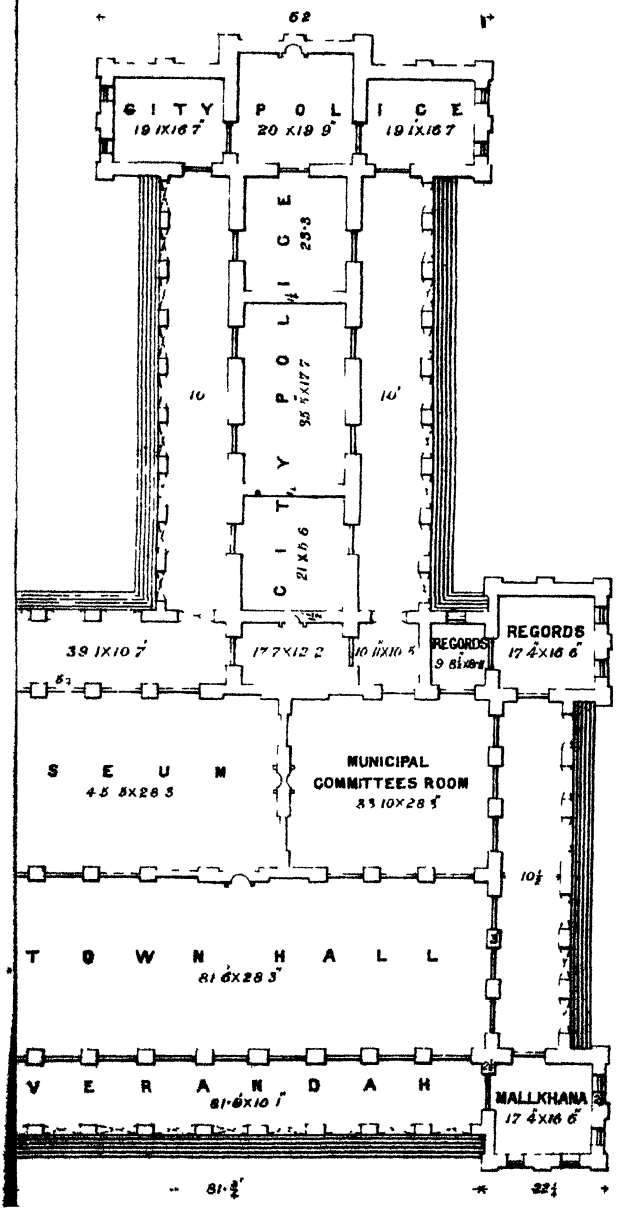
1886' 9"	c. ft. deodar wood for trusses, at Rs. 3-8 per foot, ...	Rs.	6,604
537' 6"	c. ft. deodar battens and wall plates, at Rs. 15,...	„	504
1,111	c. ft. deodar planks, at Rs. 2 per foot, ...	„	2,222
13,332	s. ft. slate covering, at Rs. 30 per 100, ..	„	4,000
		„	13,330

	Carried forward, ..	1,28,547	0	0

				Rs.	A.	P.
		Brought forward,	..	1,28,547	0	0
s. ft.						
23,492	Flooring, fine brickwork, at Rs. 22 per 100,	..	..	5,168	0	0
2,816	„ stone, at Rs. 40 per 100,	.. ..	..	1,126	0	0
42,943	Plastering small rooms, at Rs. 4 per 100,	.. ..	..	1,718	0	0
86,214	White washing and coloring, at Rs. 0-12 per 100,		..	647	0	0
43,271	Plastering large rooms, including moulding, at Rs. 8,		..	3,462	0	0
r. ft.						
2,892	Cornices of large rooms, at Rs. 80 per 100,	..	..	2,313	0	0
3,398	Cornices of small rooms, at Rs. 50 per 100,	..	..	1,699	0	0
s. ft.						
9,236	Glazed doors and windows, at Rs. 1-12 per foot,		..	16,163	0	0
1,976	Venetians, at Rs. 1-2 per foot,	.. .. ..	..	2,223	0	0
311	Iron grated doors and windows, at Rs. 2 per foot,		..	622	0	0
	Details of above iron grated Doors and Windows.					
	Bars and rods of iron 34 mds. 13 srs. 8 chit. at Rs. 17-8 per maund, ... Rs. 611					
c. ft.						
8	Of woodwork for window frames, at Rs. 1-4,	„	10			
		„	621			
r. ft.						
228	Ornamental balustrades, at Rs. 2-8-5 per foot,	..	..	576	0	0
s. ft.						
36,421	Varnishing woodwork, at Rs. 3 per 100,	.. ..	..	1,092	0	0
c. ft.						
96,045	Filling in and levelling hollows with ballast, at Rs. 3-8-0 per 100, ...		..	3,361	0	0
	Stained glass for town-hall and museum,		..	1,000	0	0
2	Ornamental turrets and vases, at Rs. 1,000 each,		..	2,000	0	0
				1,59,596	0	0
	Contingencies,	.. ..	..	1,777	4	6
	Compensation for land,	.. ..	..	8,644	0	0
	„ for approaches,	.. ..	..	2,017	0	0
	Grand total, Rs.,		..	1,72,004	4	6

LAHORE,
May, 1873.

K. L.


62
CITY POLICE
19 IX16 7"
POLICE
20 X19 9"
19 IX16 7
CITY POLICE
25·3
10
10'
95 5"X17 7
21X5 6
39 IX10 7"
17 7X12 2
10 11X10 5
RECORDS
9 8½x8½
RECORDS
17 4X16 6"
MUNICIPAL COMMITTEES ROOM
35 10X28 5"
45 8X28 3
10½
TOWN HALL
81 6X28 3"
VERANDAH
81·6X10 1"
MALKHANA
17 4X16 6"
81·8½'
22½

No. CLXX.

A NOTE ON THE "POSITION OF THE NEUTRAL AXIS IN A BEAM SUBJECTED TO TRANSVERSE STRAIN."

By Major C. A. Goodfellow, R.E.

Dated Carwar, 6th July, 1875.

The generally accepted theory, from which the formulæ commonly used for ascertaining the proper dimensions to be given to a beam subjected to cross strain are deduced, assumes that the neutral axis passes through the centre of gravity, and these formulæ are preferred to others deduced from experiments on crossbreaking, sometimes disparagingly called empirical, as more scientific and accurate; these former formulæ however only profess to be true so long as the limit of elasticity is not passed, and it is assumed that this limit is not passed in the ordinary cases which occur in practise, such as a bridge joist, or roof timber, where the material is strained to about $\frac{1}{10}$th of breaking weight.

In the "Building News," dated 16th April, 1875, there is a paper on the "Position of the Neutral Axis in a Bent Beam", which explains the generally received theory on this matter; it is stated, "theory shows that when the beam is perfectly elastic, and the bending forces are normal to the axis, and the material is not strained beyond the elastic limit, the neutral axis passes through the centre of gravity of the transverse section. Experiments have confirmed theory in this regard. But after the limit of elasticity is reached, and the ultimate strength is approached, theory fails to indicate its true position. The experiments of Barlow and others long since showed that the theory of flexure does not apply to

rupture; that is, hypotheses, that the neutral axis is at the centre of the transverse sections, and that the strains are directly proportional to the distance of the elements from the neutral axis, when applied to the strength of beams, do not give correct results": and further on, in the same paper, "the neutral axis must move from the centre as the ultimate strength is reached": the proof of this is then proceeded with, and the conclusion come to is that, "the law of internal stress is so complex, and the position of the neutral axis so indeterminate, in a condition bordering on rupture that no satisfactory theory has been established for the ultimate strength of a beam. This, however for practical purposes, is not to be regretted, since the load should not strain the material beyond the elastic limit". That is, the writer of the paper, while admitting, that the formulæ, on the assumption that the neutral axis passes through the centre of gravity, are not true, when the limit of elasticity is passed, holds (but without defining that limit) that they are good for practical purposes. To quote now from Sir W. Fairbairn's "Researches on the Application of Iron to Building," edition of 1870, page 50: "we have already observed that Tredgold and others, who have written on this subject have stated, that what was called the limit of elasticity attained by a transverse strain, was one-third the breaking weight, or in other words it did not take a permanent set, with less than that weight. Experiment by both Mr. Hodgkinson and myself have shown this to be an erroneous conclusion, as we found the elasticity injured with one-tenth, and as low as one-twelfth the breaking weight: with these comparatively slight loads a permanent set was observed which was never again restored": and further, on page 53,. . . "Mr. Hodgkinson's experiments, as well as my own, lead to this conclusion, and I have no doubt that any load (however small) producing a permanent set upon a bar, will, if taken off and replaced a sufficient number of times, eventually break it": and Rankine, when speaking of Perfect and Imperfect Elasticity (page 27, Applied Mechanics), and explaining what is meant by the limits of elasticity, does not define these "limits", or the relation between the breaking weight and the least weight producing a permanent set.

Now, in all ordinary cases, such as the bridge joist or the roof timber, precisely those conditions which Sir W. Fairbairn's and Mr. Hodgkinson's experiments go to show will produce a permanent set and also ultimately cause fracture, do exist; the timber is strained to about $\frac{1}{10}$th of its breaking weight, and there is a continual increase and diminution of pressure;

in the case of bridge joists, from the passing loads, and in the roof timber, from the ever varying wind pressure; so that it would seem that the limits of elasticity are sensibly passed in all ordinary cases; *and* if so, it follows that the formulæ for cross strain, of the theory which assumed the neutral axis to pass through the centre of gravity, are, at the least, not accurate, and in some cases may be very misleading: it would moreover, seem more logical and fair in an abstract investigation, not to assume that any substance which is known not to be perfectly elastic is practicaly so up to a certain point, only because its elasticity is not *sensibly* affected by the weight applied; no stress, however, need be laid on this if Sir W. Fairbairn's and Mr. Hodgkinson's experiment's are to be accepted.

The formulæ deduced from the theory of the assumed coincidence of the neutral axis and centre of gravity have, moreover, this disadvantage. The tensile and compressive strains, in a beam under a cross strain, are by no means applied in the same way as in the experiments for resistance to crushing and tension; whereas in the formula deduced from experiments on cross breaking, the beam in work, is strained just as was the piece of material experimented on to obtain the modulus of rupture; which, as Rankine says, page 252, "Civil Engineering," "does not always agree with the resistance of the same material to direct crushing or direct tearing, but has a special value which can be found by experiments in cross breaking only;"* a constant so obtained should not of course be used in formulæ which assume the neutral axis to pass through the centre of gravity.

If there is any force in the above reasoning, it would seem that the formulæ obtained from experiments on cross breaking, in which no assumption regarding the position of the neutral axis is made, are the more reliable, and the use of which in fact causes no discrepancy between theory and the results of experiments, other than perhaps is caused by the small scale of most experiments.

In the 1871 edition of Tredgold by Hurst, page 119, it is stated loosely that "the position of the neutral axis varies for each description of wood owing to the different degrees of resistance to tension and compression". No proof of this is given, and it hardly seems likely that it is *precisely* so,

* What is meant by the remark made in the paper in the "Building News" above quoted, viz., "that the modulus of rupture is determined only by experiment on the hypothesis that the axis remains at the 'centre' is not clear; the gist of the paper is to show that "the neutral axis moves from the centre as the ultimate strength is reached."

owing to the different way in which the tensile and compressive strains are applied, in a beam in work, and in the experiments for tension and compression; and also owing to the difference of the distances from the neutral axis to the compressed and extended surfaces: that the position of the neutral axis, for any load, varies somewhat, but not directly, as do the powers of the material to resist tension and compression seems highly probable, though to prove where it lies is a problem that has not yet been solved, or at least the solution of which is not generally known; it is not apparent that practically this is of much importance, though it is important that it should not be assumed to be where it is not.

A series of careful experiments on cross breaking, on a large scale, *i. e.*, with beams of large scantling, would be more useful than an exact knowledge of the position of the neutral axis.

C. A. G.

No. CLXXI.

WEIGHT ON FOUNDATIONS OF BUILDINGS IN BENGAL.

[*Vide* Plate XLV.]

Extract from the Narrative Progress Report of the Government of Bengal, P. W. Department, for the year 1873-74, *by* H. LEONARD, ESQ., *M. Inst. C.E., Offg. Chief Engineer, Bengal.*

17th May, 1873.

THOUGH few, if any, of our buildings in Bengal have fallen, many of them cracked, some of them badly. On commencing several new buildings in Calcutta last year, we naturally considered the question whether we could do anything to prevent bad cracks and settlements. The cause of both settlements and cracking seemed to be the compression of the soil under the buildings, and taking this view of it, the question arose, what is a safe weight to put on this Bengal alluvial soil without causing serious disturbance of it? Finding nothing at all reliable on the subject, we decided on making a small series of experiments at Akra, where facilities were available or near at hand.

Weight on foundation-bed.—*Series No.* 1 gives the result of the trials made. The scale on which they were made was not a mere toy scale, the piers of masonry dealt with, were such as might be used on real work, and though the results may not be an infallible guide, they certainly do give definite information; they show beyond doubt that with a weight of one ton to the square foot, the compression of the earth is very small; in fact, what might be due to disturbance of the surface in opening the foundations; while with two tons to the foot, sinking is decided, quite enough to cause bad cracks. If one part of a building were built with a load of one ton to the foot, and other parts with a load of two tons to the foot, the building would certainly crack; and if other parts were built with a weight of three tons to the foot, there would be very bad cracks.

I consider that safe conclusions to draw from the results of the

experiments are these. If it be desired to provide against sinking of *the whole structure*, the weight per foot on the earth, whatever may be the *depth* at which the foundation is laid, should not be more than one ton per square foot; and that, if *unequal sinking-cracks* are to be provided against, the weight on all parts of the foundations should be equal per square foot; unless that the most heavily loaded portion carries less than one ton per square foot: with this weight, and of course with lighter weights, no perceptible compression takes place, and hence no unequal settlement would occur from unequal loading.

Depth at which Foundations may be laid.—The next point for experiment was,—at what depth is the soil best fit for building on? We had trials made at depths of *two feet six inches*,—that is, just below the usually disturbed soil; at *four feet*, where the true alluvial deposit was undisturbed: at *eight feet*, where a different though not better soil was touched; and at *eleven feet*, where the soil was wet and soft. All through this series, the effects of weight per foot considered in the above paragraphs were kept in view. *Series No.* 1 gives also the results of the experiments.

SUMMARY.

No.	Depth of foundation below surface of the ground.	MAXIMUM SINKING, WITH WEIGHT PER SQUARE FOOT OF			Remarks.
		1 ton	2 tons	3 tons	
		Sinking.			
		inch.	inch.	inch.	
1	2 feet 6 inches, ...	$\frac{5}{16}$	$2\frac{1}{8}$	$7\frac{7}{8}$	Including the weight of brickwork.
2	4 feet, ...	$\frac{5}{16}$	1	$8\frac{1}{16}$	
3	8 „	$\frac{3}{16}$	$\frac{11}{16}$	$1\frac{13}{16}$	
4	11 „	$1\frac{1}{16}$	$8\frac{1}{4}$	$7\frac{1}{4}$	Exclusive of ditto.

The conclusions which may be drawn from the results of these trials are not so clear as they are in the case of the weight on foundation; but it is evident that shallow foundations have the disadvantage of being affected by climatic influence, as heavy rain caused the masonry laid at a depth of two feet six inches below the surface to sink considerably. Again, it appears that foundations laid at a depth of eleven feet below the surface, sink more than those laid at depths of four feet and eight feet. This is difficult to explain. It may be that, when the foundations are opened to a depth of eleven feet, the bottom, relieved of

WEIGHT ON FOUNDATIONS OF BUILDINGS IN BENGAL.

Scale 1 inch = 8 feet

Fig 1

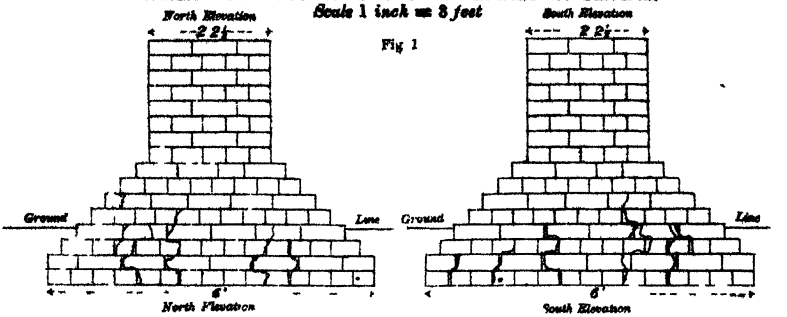


Fig 2

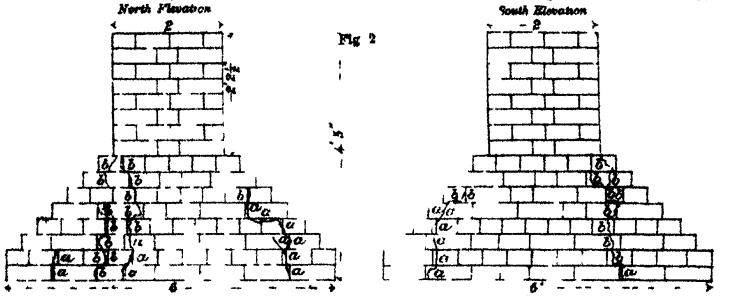


Fig 3

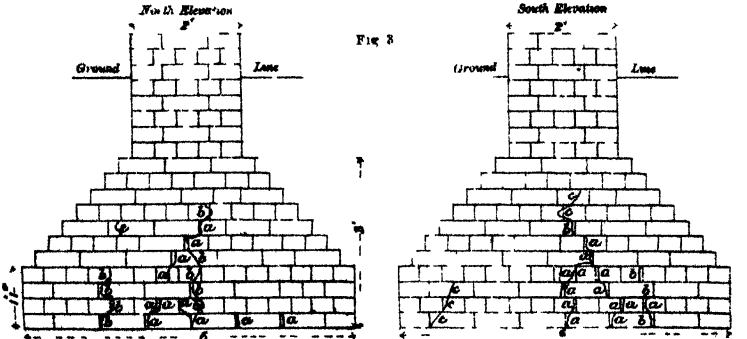
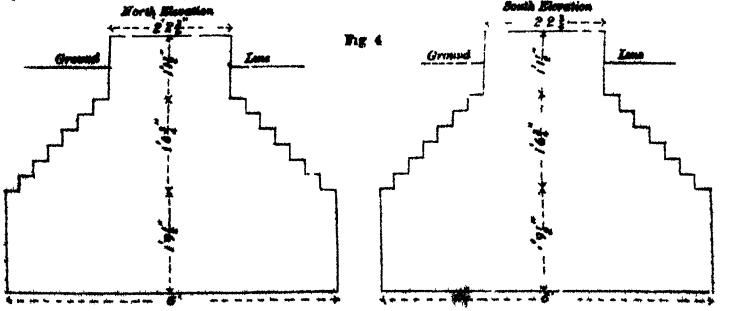


Fig 4



such a weight of earth, "blows up" a little, though hardly perceptibly, and the first effect of weighting it is to force this blown-up surface down to its original state, but that, when thus pressed down to what it was before the earth was removed from it, it may bear pressure as well as the earth at smaller depths. The conclusions which I am inclined to draw from the experiments are these:—The foundations of important buildings should be laid so deep that they cannot be affected by climate. The ground if undisturbed, is as good at a depth four feet below the surface as it is at greater depths, and it is about the same up to eight feet deep. I would lay it down as a rule, that in undisturbed alluvial soil, foundations of *important buildings* should not be laid at a less depth than four feet, nor at a greater depth than six feet.

Strength of Spread Foundations.—Having settled on one ton to the square foot as the weight to be carried on the soil, it became necessary to spread out the foundations a good deal to get the area required, and then the question arose, at what angle should they spread, o what depth of masonry should there be at the weakest point? Some sections of foundations which I saw, seemed to me to be too weak. In order to help to settle the question, I had the experiments *No.* 2 *Series* made; the result may be practically stated thus,—for a pressure of one ton to the foot, on Bengal soil, the thickness at the toe of the slope should not be less than one foot six inches (*see* record of experiments) and the stepping at an angle of not more than 45°. I take one foot six inches, because with a thickness of nine inches, the projections broke off as shown in *Figs.* 1 and 2 of the Plate, while with a thickness of one foot nine inches, no symptoms of weakness showed, even when the work was fresh. With good masonry, of mortar which will set in damp or wet, I feel certain that the dimensions given above are enough; but with bad masonry—bad from whatever cause—considerably more strength should be given.

I think it likely that this question of footings *breaking off* has not been sufficiently attended to; the result of such an occurrence can be seen by looking at *Fig.* 1 of the Plate where, instead of an area of twelve feet, that is, the width of the footing by two feet long to rest on, the area is reduced, by the outer sides breaking off, to less than half; that is, to the width between the cracks by two feet; and instead of a weight of one ton per foot on the foundation soil, we should have a weight of over two tons, which means a subsidence of two or three inches, and cracks of probably he same width.

FIRST

Experiments made at Akra for the purpose of testing what weight the *sents Lower Ben-*

Number of experiment.	Depth below surface of ground.	Size of pier constructed.	Total height of pier.	Materials.	Total contents of pier.	Weight of pier at 100 lbs. per c. ft.	Superficial area of pier.	Age of pier.
	ft. in.	ft. in.	ft. in.		c. ft.	tons. cwt. qr. lbs.	s. ft.	days
*1	1 4	3 2½ square.	2 11½	Bricks with mortar, two of soorkee to one of lime,	30·88	2 3 0 8	10·29	6
†2	2 6	3 2½	5 0½	Ditto ditto,	51·89	2 6 1 9·4	10·29	...
3	2 6	3 2½	5 0½	Ditto ditto,	51·89	2 6 1 9	10·29	...
4	2 6	3 2½	5 0½	Ditto ditto,	51·89	2 6 1 9	10·29	...
5	4 0	2 9½	5 9	Ditto ditto,	42·12	1 17 2 12	7·76	...

* The object of this experiment was to ascertain whether the ground under the masonry alone is
† The object of this, and the eleven following experiments, is to show the compression of the soil
‡ The frame carrying the load was supported by screw-jacks at each corner during the work of bear on the masonry.

SERIES.

ordinary undisturbed alluvial soil of Calcutta, which fairly repregal soil, can bear.

Load, excluding weight of pier.	Weight per sq. ft., *including weight of pier.*	RESULT OF LOADING.		REMARKS.
		Days.	Sinking.	
tons. cwt. qr. lbs.	tons. cwt. qr. lbs.			
41 0 0 0	4 3 3 13·8	1st	$1\frac{7}{8}$	The pier sank $3\frac{6}{8}$ inches with this load by compressing the ground on which it stood; the surrounding ground was not visibly disturbed, except for a distance of about 2 or 3 inches immediately in contact with the pier, which seemed to be caused by friction on two sides, the load being slightly in excess on those sides. From this experiment it would appear that only the ground under the masonry sinks, the surrounding ground not being disturbed to any appreciable extent.
		2nd	...	
		3rd	$3\frac{6}{8}$	
10 7 3 8	1 4 2 20·3	1st	$\frac{3}{16}$	Immediately on lowering screw-jacks.‡
		2nd	$\frac{4}{4}$	
		3rd	$\frac{5}{16}$	
20 14 2 19	2 4 3 5·6	1st	1	On lowering screw-jacks.
		2nd	$1\frac{2}{8}$	
		3rd	$1\frac{13}{16}$	
		4th	$1\frac{7}{8}$	
		5th	2	
		6th	$2\frac{1}{8}$	
		7th	$2\frac{2}{8}$	
31 1 2 3	3 4 3 17·2	1st	$5\frac{1}{8}$	Ditto ditto.
		2nd	$5\frac{2}{8}$	
		3rd	$5\frac{3}{8}$	Very heavy rain fell on the night of the 4th.
		4th	$5\frac{4}{8}$	
		5th	$6\frac{5}{16}$	The sinking of this block is considerably more than in experiments which were 4 feet and 8 feet, respectively, below the ground level; a good deal of rain fell during the time this experiment was in progress, and the soil to the depth of foundation was no doubt saturated.
		6th	$7\frac{5}{16}$	
		7th	$7\frac{7}{16}$	
		8th	Not measured	
		9th	$7\frac{7}{16}$	It shows fairly the danger of shallow foundations.
		10th	$7\frac{11}{16}$	
7 16 2 21	1 5 0 4·3	1st	$\frac{3}{16}$	Immediately on lowering the screw-jacks. No further sinking took place with this weight for a space of seven days.

compressed, or whether the compression extends for some distance round the foundation.

at different depths and under different weights.

loading; when the desired load was on, the screw-jacks were lowered, and the load was brought to

First

Number of experiment.	Depth below surface of ground.	Size of pier constructed.	Total height of pier.	Materials.	Total contents of pier.	Weight of pier at 100 lbs. per c. ft.	Superficial area of pier.	Age of pier.
	ft. in.	ft. in.	ft. in.		c. ft.	tons. cwt. qr. lbs.	s. ft.	days
6	4 0	2 9½	5 9	Bricks with mortar, two of soorkee to one of lime.	42·12	1 17 2 12	7·76	...
7	4 0	2 9½	5 9	Ditto ditto,	42·12	1 17 2 12	7·76	...
8	8 0	3 2½	10 6½	Ditto ditto,	108·50	4 16 3 14	10·29	...
9	8 0	3 2½	10 6½	Ditto ditto,	108·50	4 16 3 14	10·29	...
10	8 0	3 2½	10 6½	Ditto ditto,	108·50	4 16 3 14	10·29	...
11	11 0	3 2½	14 0½	Ditto ditto,	144·53	6 9 0 5	10·29	...

SERIES (*Continued*).

Load, excluding weight of pier.	Weight per sq. ft., *including weight of pier.*	Result of Loading. Days.	Result of Loading. Sinking.	Remarks.
tons. cwt. qr. lbs.	tons. cwt. qr. lbs.			
15 10 3 22	2 4 3 17·4	1st	$\frac{9}{16}$	
		2nd	$\frac{15}{16}$	
		3rd	$\frac{15}{16}$	
		4th	$\frac{15}{16}$	No further sinking took place.
23 5 0 24	3 4 3 5·2	1st	$1\frac{1}{4}$	On lowering screw-jacks.
		end of 1st	$2\frac{1}{8}$	
		3rd	3	
		5th	$3\frac{1}{4}$	No further sinking.
				The Executive Engineer states—"heavy rain fell during part of the time of the last loading by which the ground was flooded, and most probably water percolated to the foundation. This, combined with very strong wind blowing from the south and east, caused the unequal settlement of the block."
10 6 0 20	1 9 1 22·5	1st	$\frac{3}{16}$	No sinking was observed from the 2nd to the 7th day.
20 13 0 3	2 9 2 5·9	1st	$\frac{9}{14}$	
		2nd	$\frac{9}{16}$	
		3rd	$\frac{8}{8}$	
		4th	$\frac{11}{16}$	
		5th	$\frac{11}{16}$	
		6th	$\frac{11}{16}$	
		7th	$\frac{11}{16}$	
30 19 3 14	3 9 2 17·4	1st	$1\frac{1}{8}$	The result of this experiment tends to show that the bearing power of soil at 8 feet depth is no better for light weight than at 4 feet, but for heavy weight it seems to bear more.
		1st	$1\frac{1}{8}$	
		3rd	$1\frac{11}{16}$	
		4th	$1\frac{11}{16}$	
		5th	$1\frac{3}{4}$	
		6th	$1\frac{3}{4}$	
		7th	$1\frac{3}{4}$	
		11th	$1\frac{13}{16}$	
10 7 3 27	1 12 3 0·8	1st	Nil	On lowering screw-jacks.
		end of 2nd	$\frac{3}{16}$	Extra load put on to make the weight equal to a ton to the foot, exclusive of brickwork.
		3rd	$\frac{7}{16}$	
		4th	Sunday	
		5th	$\frac{13}{16}$	
		8th	$\frac{7}{8}$	
		9th	$\frac{15}{16}$	In this, and the two following experiments, the foundation carried more than in the preceding experiments. But even allowing for this, the ground seemed to be capable of bearing less at 11 feet than at 4 or 8 feet.
		10th	1"	
		12th	1"	
		13th	$1\frac{1}{16}$	

FIRST

Number of experiment.	Depth below surface of ground.		Size of pier constructed.		Total height of pier.		Materials.	Total contents of pier.	Weight of pier at 100 lbs. per c. ft.				Superficial area of pier.	Age of pier.
	ft.	in.	ft.	in.	ft.	in.		c. ft.	tons.	cwt.	qr.	lbs.	s. ft.	days
12	11	0	3	2½	14	0½	Bricks with mortar, two of soorkee to one of lime.	144·63	6	9	0	5	10·29	...
13	11	0	3	2½	14	0½	Ditto ditto,	144·63	6	9	0	5	10·29	...
14*	4	0	2 square	10	7	4½	Third class Akra bricks with mortar composed of two of soorkee to one of lime.	59·20	2	12	3	12	8·03	15

* The object of this experiment was to ascertain if

SERIES (*Concluded*).

Load, excluding weight of pier.	Weight per sq. ft., *including weight of pier.*	RESULT OF LOADING		REMARKS.
		Days.	Sinking.	
tons. cwt. qr. lbs.	tons. cwt. qr. lbs.			
20 17 0 23	2 13 0 9·5		$1\frac{1}{8}$″	On lowering screw-jacks.
		1st	3″	
		2nd	3″	
		3rd	3″	
		4th	Sunday	
		5th	$3\frac{1}{8}$	
		6th	$3\frac{3}{16}$	
		7th	$3\frac{3}{16}$	
		8th	$3\frac{7}{16}$	
		9th		
31 4 0 6	3 13 0 20·5	1st	$3\frac{3}{4}$″	Ditto ditto.
		2nd	$6\frac{1}{16}$	
		3rd	Sunday	I think the greater sinking in the case of this pier may be explained in this way. At a depth of 11 feet, the ground, which gets soft, *rose* before the load was put on, and hence sunk more when again under heavy pressure.
		4th	$6\frac{1}{8}$	
		5th	$6\frac{1}{16}$	
		6th	$6\frac{1}{16}$	
		7th	7	
		8th	7	
		9th	$7\frac{1}{16}$	
		10th	Sunday	
		11th	$7\frac{1}{8}$	
		12th	not measured	
		13th	$7\frac{1}{8}$	
		14th	$7\frac{1}{16}$	
		14th	$7\frac{1}{16}$	
		15th	$7\frac{1}{16}$	
		16th	$7\frac{1}{4}$	
		17th	Sunday	
		18th	$7\frac{5}{16}$	
8 0 0 0	1 6 2 0·7	1st	$\frac{1}{8}$	The pier loaded with one ton per foot was left standing for three months, but no further sinkage than what was recorded on the 14th day was discovered during the remainder of the time.
		7th	$\frac{1}{4}$	
		14th	$\frac{5}{16}$	

without adding weight sinking occurred from long standing

SECOND

To test the Strength of

No.	Foundation of pier.	Plinth of pier.	Foundation of pier below ground level.	Age of pier.	Quality of bricks and proportions of ingredients.	Total load.			
						tons.	cwt.	qr.	lbs.
1	6′ × 2′	2′ 2½″ × 2′ × 2′	1′	19 days.	1st class Akra bricks, and mortar composed of two of soorkee to one of lime.	12	1	0	14
2	6′ × 2′	2′ × 2′	4′ 6″	3 months & 2 days old.	Ditto,	20	18	1	16·83

SERIES.

Splayed Foundations.

Position of cracks.	Remarks.
Vide *Fig.* 1.	The pier was constructed on the natural soil and loaded at the rate of 1 ton 38½ lbs. per square foot. On lowering the screw-jacks, 2 bricks and 17 mortar joints on the north, and 2 bricks and 9 mortar joints on the south, cracked, and as the load preponderated more on the north side, the wall on that side sunk about half an inch in the centre, and was 2 inches out of plumb. *2nd day* it was seen that the former cracks on both sides became wider by 1 brick and 2 mortar joints on the north, and 1 brick and 14 mortar joints on the south, side. *3rd day.* Sunday. No observations taken. *4th day.* No further cracks appeared, but the former ones became rather wider. Additional load of quarter ton per foot was put on, when the pier sank about 3 inches on the south side. If concrete were added, of course it would be stronger, but this was to test the strength of the masonry, not of masonry and concrete.
Vide *Fig.* 2.	Experiment on splayed foundation wall having a footing of 6 inches in depth and off-sets being at an angle of 45°. With ¼ ton load to the foot, which remained on one hour, no perceptible disturbance. With ½ ton to the foot no perceptible disturbance. „ ¾ „ „ „ „ „ 1 „ to the foot, which remained on all night, 13 hours, nothing perceptible. „ 1¼ ton to the foot, one hour on, the wall slightly sunk in the ground, no disturbance in the brickwork. „ 1½ ton to the foot, one hour on, slight cracks appeared in the wall, marked *a* on the elevation. „ 1¾ ton to the foot, the former cracks became wider and additional cracks in the wall took place, which are marked *b* on the elevations. The cracks in the two lowest courses were about three-quarter inch in width. The wall sunk about half a brick in the ground, settlement being fairly even. Executive Engineer adds, that the Experiment No. 1 was on a wall similarly constructed to the one herein reported, but was only 19 days old. On comparing the two experiments, the difference in the strength of foundations is very marked, and this no doubt is owing to the difference in the age of the masonry, 19 days and 3 months. The masonry of this trial was very carefully built, good hands and good mortar, most probably better work than could be expected in all parts of the foundations of a large building, and was kept free from all extraneous moisture ; it cracked with a load of 1¾ tons to the foot. This is not much in excess of the weight on foundations of some of the large buildings in Calcutta, it is believed ; it would, therefore appear to be too weak in design to leave a safe margin for indifferent or careless work, and other contingencies.

SECOND

To test the Strength of

No.	Foundation of pier.	Plinth of pier.	Foundation of pier below ground level.	Age of pier.	Quality of bricks and proportions of ingredients.	Total load.			
						tons.	cwt.	qr.	lbs.
3	6′ × 2′	2′ × 2′ × 2′1½″	4′6″	15 days.	1st class Akra bricks, and mortar composed of two of soorkee to one of lime.	27	1	1	12
4	6′ × 2′	2′ 2½″ × 2″ × 2′1½″	4′	15 days.	Ditto,	11	9	2	10
5	6′ × 2′	2′ 2½″ × 2′ × 2′1½″	4′	3 months	Ditto,	23	18	0	0·16

SERIES.

Splayed Foundations (Concluded).

Position of cracks.	Remarks.
Vide *Fig.* 3.	With ¼ ton to the foot, one hour on, no disturbance perceptible. " ½ " " " " " ¾ " " " " " 1 " " " " " 1¼ " " " " " 1½ " " a very slight settlement in the ground, but no disturbance of the brickwork. With 1¾ ton to the foot, one hour on, the foundation sunk in the ground a little more, about half an inch, and the masonry cracked slightly, as shown at the places marked *a* in *Fig.* 3. With 2 tons to the foot, one hour on, the load remained on all night, 13 hours, the former cracks marked *a* became a little wider, and the additional cracks marked *b* were shown. With 2¼ tons to the foot, one hour on, the former cracks marked *a* and *b* became a little more open, and the fresh cracks marked *c* appeared. The wall sunk about 2 inches on south side, and not quite so much on the north side. *Remarks by the Executive Engineer*— This mode of giving footings to foundations is a mean between those shown in Nos. 1 and 4, which were all green masonry 19 and 15 days old.
Vide *Fig.* 4.	The weight was put on the plinth, the off-sets being at an angle of 45°, commencing from the height of 1′ 9½″ of masonry. No crack in the masonry was visible after being weighted 30 hours, when the load and pier tipped over on the south side. The soil below was soft from moisture, the heavy rain that fell on the 24th and 25th of last month having saturated the ground.
Vide *Fig.* 4.	The masonry is the same as No. 4, only older. With ¼ ton to the foot, one hour on, no disturbance. " ½ " " " " ¾ " " " " 1 " " " " 1¼ " " foundation sunk slightly, but no disturbance in the masonry. With 1½ tons to the foot, one hour on, foundation sunk more, but no disturbance in the masonry. With 2 tons to the foot, 13 hours on, foundation sunk one brick, but no disturbance in the masonry. This experiment shows that a foundation of this shape is rather too strong.

H. L.

NAWAB SALAR JUNG BAHADUR

No. CLXXII.

THE 'KURRACHEE' MORTAR-TESTING MACHINE.

[*Vide* Plate XLVI.]

Note by J. H. E. HART, ESQ., M.I.C.E., *Supdt., Kurrachee Harbor Works.*

Dated Manora, 26th May, 1875.

THE accompanying drawing represents a Mortar-Testing Machine, recently made up in the Kurrachee Harbor Workshops for the Superintending Engineer, Indus Valley State Railway.

The machine is simple and inexpensive, costing under Rs. 100, and may be made of very considerable power, although, not equal to that required for experiments on Portland Cement.

The machine from which the drawing was made gave a Tensile Stress of 200 lbs. on 2¼ square inches, equal to 88 889 lbs. per square inch.

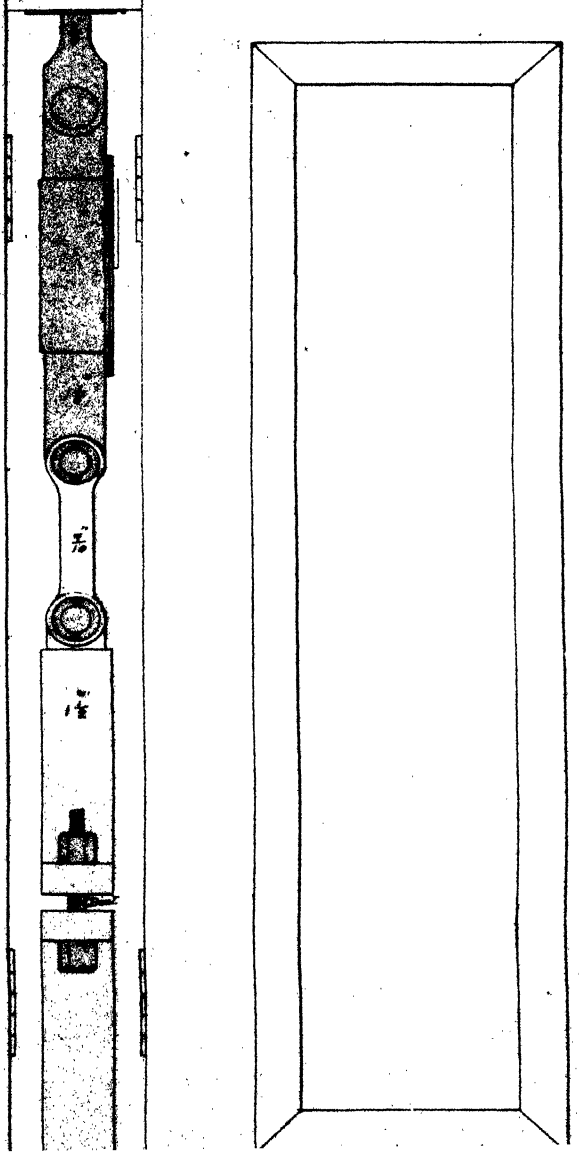
The case of the machine forms its stand; its doors, when opened for use, giving stability. A Salter's Balance registers the stress,—the wheel, at top, and screw affording the power. The clips for the mortar block are similar to those used by Grant. The bolts *a*, *a*, should be quite slack.

Such small portable machines would be valuable in Executive Engineer's Offices, to enable the builder to test the absolute and relative values of the various mortars used, or proposed in a district.

The details of the machine have been skilfully worked out by Mr. Sangster, the Mechanical Engineer of the Harbor Works.

J. H. E. H.

SIDE ELEVATION.



NAWAB SALAR JUNG BAHADUR.

No. CLXXIII.

EXPERIMENTS ON BRIQUETTES OF CEMENT FOR NARORA WEIR.

Report by M. KING, ESQ., *Assist. Engineer, on the Manufacture of Experimental Bricks of Mortar and Cement.*

Dated Aligarh, the 4th July, 1872.

To carry out the necessary Experiments, there are required—

(*a*).—A small brick furnace and bellows.

(*b*).—A temporary shed to afford protection against the weather.

(*c*).—Material to experiment on (*i. e.*, nodular and block kankar), and labor, fuel, &c., for conducting operations.

And the cost of these will amount to Rs. 200.

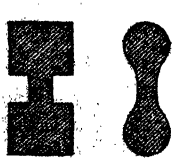
The general object is—

(*d*).—To ascertain the quality of the limestone available for the construction of the weir.

(*e*).—To test the strength of different kinds of mortar made from the available limestone.

(*f*).—To decide whether it would be cheaper to manufacture an artificial cement for our béton blocks and hydraulic works, or to import it from England.

With this object in view, it is proposed to obtain from two feet to five cubic feet of kankar direct from each of the available quarries, and to calcine the limestone thus obtained in a furnace. Samples of mortar, formed (as shown in the margin) of different proportions of lime, sand, and surkhi, will then be made and allowed to set in moulds under still-water. The strength of these bricks of mortar (as regards tenacity and resistance to attrition) will next



be tested in the manner recommended by Colonel Brownlow (*vide* Paper No. LXII., Vol I., Professional Papers), [Second Series].

For the manufacture of an artificial cement, the Chief Engineer's suggestion to mix the *hydrate* of kankar lime with various clays in certain proportions will be acted up to. It is possible, however, that a better cement may be made by substituting (as in the manufacture of Portland cement) an impure *carbonate* of lime (*i. e.*, nodular kankar) reduced to an impalpable powder, for the *hydrate* recommended above. The process will certainly be more expensive, but it is worth a trial.

The furnace when filled will contain about five cubic feet of stone and fuel, and may be used either as a "perpetual" or an "intermittent" kiln.

Charcoal will be the fuel employed, and as it is doubtful whether the needful degree of heat will be generated in so small a kiln, it is decided to employ a pair of powerful bellows.

Note by M. KING, ESQ. *Asst. Engineer, &c.—Dated the 2nd May*, 1873.

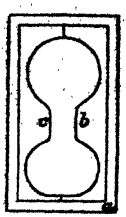
The object of these experiments was to ascertain the quality of the kankar in the vicinity of Narora, and to determine whether it was possible to manufacture an artificial cement out of the natural products of the Doab.

Nodular kankar was the only stone used in the manufacture of bricks of mortar. It was first broken into small pieces (none being larger than a walnut), washed, and then calcined in a furnace with charcoal fuel; the proportion of fuel to kankar varied from $\frac{1}{2}$ to $\frac{1}{3}$. The calcined kankar was next ground between a pair of stones to an almost impalpable powder, worked up in a box with the addition of water to the consistency of a stiff paste, and then placed in moulds. It may be objected that washing and grinding the kankar to an almost impalpable powder are refined processes that cannot easily be carried out in actual practice, and that the experiments are therefore of not much value. Such an objection should not have much weight at present, because if experiments prove that by washing the kankar (the same end, viz., removal of dirt, can also be attained by breaking the kankar into small pieces and then screening it) and grinding the lime into a fine paste, we obtain a great increase in tenacity, the extra cost would be a minor consideration in the case of the heavy works contemplated at Narora.

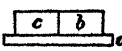
Previous to my transfer to the Narora Division I had made up 156 bricks of mortar and two béton blocks. Great difficulty was experienced,

as will be seen from the out-turn, in preventing cracks in the bricks during the process of setting and removal from moulds; out of the 156 samples mentioned above, only 32 were fit to be tested for tenacity. I have since discovered that this difficulty of obtaining sound bricks can be entirely overcome by careful attention to the following points:—

Plan.



End elevation.



a—*Bottom of mould.*
b—*One side of ditto.*
c—*The other side of ditto.*

The mould should be of three movable pieces of wood (*a*, *b*, and *c*) and of the pattern shown in the sketch; it is quite unnecessary to secure the bottom piece *a* to the sides *b* and *c*.

Each mould should be soaked in water for 24 hours before it is filled with mortar, the object being to prevent expansion of the wood after the mould has once been filled with mortar. Numerous trials have convinced me of the fact that a dry mould filled with mortar invariably causes the brick to crack.

The bottom of each mould should be sprinkled with sand or surkhi, to allow of the easy separation of the brick from the wood.

The side pieces should be held firmly together during the process of filling the mould, which should then be carefully removed to a trough in which the water is about half an inch below the top of the mould. If the moulds are submerged, it is evident that the side pieces will (unless they are weighted) float, and soon destroy the brick. The side pieces should be removed after 24 hours, the bottom piece, with the sample brick on it, being allowed to remain either in water or in some place where it can be kept tolerably moist. At the end of a week the sample brick should be removed from the bottom piece. This is best done by holding that piece of wood "on end," by placing one hand under the lower head of the sample and by gently tapping the wood against the floor with the other. After separation the sample bricks should be placed in rows on end, the bricks of the first row resting against a moist wall, those of the second resting against the first, and so on. They should be watered with a rose three or four times a day for about a month, and then allowed to dry in a room till it is decided to test them.

I have have entered into the above details to save others the disappointment I experienced when I first started the manufacture of these

experimental bricks of mortar. By attending to the precautions I have succeeded in obtaining, since may return from the Narora Division, over 90 sound samples.

The accompanying Table A. shows the tenacity in lbs. per square inch, composition, and age of nine samples that will be forwarded to the Executive Engineer of the Narora Division. The tensile strength of the bricks marked T and U, which were unfortunately broken in removal from moulds, could not be ascertained.

In my endeavour to manufacture an artificial cement I adopted the process of first grinding the raw kankar into an impalpable powder and then mixing it with clay in proportion of 2 to 1, 3 to 1, 4 to 1, and 5 to 1; the ingredients were thoroughly intermixed in a box with the addition of water, formed into balls, dried in the sun, and burnt to a semi-vitrified state in a furnace with charcoal. In some instances I regarded the kankar as a natural cement stone, and with a view to obtaining a homogeneous cement, merely reduced it to an impalpable powder which was mixed with water, formed into balls and calcined in the usual way. I I regret I cannot yet, owing to the great failure in the out-turn of bricks, state the proportion of kankar to clay that is likely to give the best result, but I hope to determine this point before I have done with these experiments.

Since my return from the Narora Division I have been working on a system that should afford some valuable information when the bricks have been tested. I think it may be taken for granted that the limestone for the Narora Weir will be obtained principally from the quarries of Muhammadpur, Pahokarpur, Baloni and Akbarbur; believing this to be the case, I have obtained from each quarry a cartload of material which is being treated in the following manner:—

A certain quantity (about $\frac{2}{3}$rds of a cartload) of the kankar from each quarry is calcined, ground to an impalpable powder, and formed into sample bricks, some of which are composed of pure lime, and the rest of the same lime mixed with surkhi in proportion of

6	parts of lime in paste to		1	of surkhi in	powder.
5	ditto	ditto	1	ditto	ditto.
4	ditto	ditto	1	ditto	ditto.
3	ditto	ditto	1	ditto	ditto.
2	ditto	ditto	1	ditto	ditto.
1	ditto	ditto	1	ditto	ditto.

The remaining kankar from each quarry is ground into an impalpable powder and mixed with clay or other ingredients in various proportions with the object of manufacturing an artificial cement.

I hope to have, in the course of the next six weeks, nearly 300 bricks of mortar, which might be made over to the Executive Engineer of the the Narora Division for the purpose of testing their tencity. I am preparing a Table showing the mark on each sample, its composition, date of manufacture, &c., so that there may be no difficulty in deducing practical results after the bricks have been tested.

Major Helsham Jones suggestion to make up a testing-machine should be carried out; it is a most painful undertaking to test some hundreds of samples by the primitive process of fixing one end of a brick and suspending weights to the other till fracture occurs.

The two béton blocks, of which a description is given below, were thrown into the second bay (counting from the left bank) of the Someyra Falls, Ganges Canal, in the first week of April 1873. It should be borne in mind, when they are taken out for inspection, that their sharp edges were lost during removal from the moulds.

Béton block No. 1, measuring 2′ × 1′ × 9″, was manufactured on the 9th August, 1872, of block kankar chips and mortar, in the proportion of three parts of the former to one of the latter measured in paste; the mortar consisted of equal parts of surkhi and kankar lime measured dry. The material was rammed for ten hours, in layers of three inches, in a strong wooden frame, by two men with a rammer weighing 18 lbs. The block was watered three times a day for a month after manufacture, and then allowed to dry in a room. Its weight in April last, before immersion, was 214 lbs., *i. e.*, 142·7 lbs. per cubic foot.

Béton block No. 2, measuring 2′ × 1′ × 9,″ was manufactured exactly in the same manner on the 10th November, 1872, of the following in gradients:—

Five parts block kankar chips.

Two parts of mortar (measured in paste) made from kankar lime without any admixture.

The weight of this block in April last, before immersion, was 200 lbs., *i. e.*, 133·3 lbs. per cubic foot.

TABLE A.

Mark on sample.	When manufactured.	Age in days on date of fracture.	Tenacity in lbs. per square inch.	REMARKS.
P.	21st October, 1872,	139 days,	118·06	Made from an artificial cement consisting of four parts of kankar powder to one part of Narora clay.
V.	5th November, 1872,	131 days,	134·72	Made from an artificial cement, consisting of kankar powder only mixed with water, dried in the sun and thoroughly calcined, but not vitrified.
U.	2nd November, 1872,	...	..	Made from exactly the same cement as sample V; slightly vitrified pieces were, however, selected for this sample.
B.	28th September, 1872,	194 days,	108·06	From an artificial cement made by grinding kankar to powder, mixing with water, drying and then calcining.
C.	23rd August, 1872,	212 days,	210·26	Made from kankar lime without any admixture. Fracture did not occur at the weakest point of the sample, and was due to the existence of an air bubble in the mortar; the actually breaking weight of the sample may therefore be taken at a higher figure than 210·26 lbs. per square inch.
Y.	12th November, 1872,	131 days,	115·23	Made from kankar lime (same as that used for béton block No. 2), without any admixture.
Q.	21st October, 1872,	153 days,	106·82	Made from kankar lime without any admixture.
T.	2nd November, 1872,	..	..	Made from artificial cement, consisting of kankar powder, only mixed with water, dried in the sun and thoroughly calcined but not vitrified.
A.2.	28th March, 1873, ..	..	..	Made from kankar lime without any admixture. The kankar was obtained from the Akbarpur quarry (the same as is used on the Rajghat road). This is sent as a sample of an entire brick; its tenacity should be tested after it is three months old.

Note by M. KING, ESQ., *Asst. Engineer, &c.—Dated the* 11*th March*, 1874.

THE samples of *mortar* were in every case subjected to the following process:—

The kankar from the quarry was first broken into small nodules (none larger than a walnut), thoroughly washed, and then calcined in a furnace with charcoal as fuel; the under-burnt and highly vitrified pieces were rejected; the calcined stone was ground in a hand flour-mill to a fine powder, and then worked up in a box, with the addition of water, to a stiff paste; a portion of this paste was put into moulds for such samples as are shown in Table B. to contain nothing but kankar lime. The remainder of the paste was then mixed with surkhi (measured dry) in different proportions to ascertain (hereafter by actual tests) the effect of the admixture on the tenacity of the mortar.

Cements.—The following plan of operations was adopted as regards the stone from each quarry (Akbarpur, Baloni, Muhammadpur and Pahokurpur):—

A portion of the raw stone, after being broken into nodules and thoroughly washed, was ground to a very fine powder in a hand flour-mill. The powder was then mixed (dry) with clay (and in some cases with fat lime in the proportions shown in Table B.; water was next added to the mixture, which was agitated till it attained the state of a semi-fluid; the mixture was then allowed to stand till it became firm enough to be made up into balls (about an inch in diameter); the balls were thoroughly dried in the sun and calcined in a furnace with charcoal; the under-burnt and highly vitrified pieces were rejected, and the remainder of the cement was ground into an impalpable powder, mixed with water, and placed in moulds. *All* ingredients that enter into the composition of cements were *measured* in a state of powder. In some cases the cement consisted merely of kunkar ground into a powder, worked up into a paste with water, and then dried and calcined. (Samples marked A.15, M. and Xx., illustrate this process of manufacture).

The lime used in samples P.1 and P.9 was taken from the same kiln; in samples P.1 *all* under-burnt and vitrified pieces were rejected; in samples P.9 the proportion of under-burnt and vitrified pieces actually found in practice was allowed.

The béton blocks were manufactured after the manner described by me in my first Note, copy of which was forwarded to the Narora Division with this office No. 1697, dated 2nd May, 1873. The samples of mortar and cement, after being placed in the moulds, were treated in the manner recommended in that Note.

TABLE B.

Table showing date of manufacture and ingredients used in the Sample Bricks and Mortar.

Distinguishing mark of sample.	INGREDIENTS.		Date of manufacture.	REMARKS.
	Parts of lime or cement measured in paste.	Parts of surkhi measured dry.		
A. 1	1 of K. L.	..	22nd March, 1873	Ordinary kankar lime from Akbarpur quarry.
A. 3	4 of K. L.	1	28th ditto ..	Ditto ditto ditto ditto.
A. 4	5 of K. L.	1	Ditto ..	Ditto (same lime as in A.3.)
A. 5	1 of K. L.	..	29th ditto ..	Ordinary kankar, Akbarpur quarry.
A. 6	3 of K. L.	1	Ditto ..	Same lime used as in A.5.
A. 7	4 of K. L.	1	Ditto ..	Ditto ditto.
A. 8	1 of K. L.	..	30th ditto ..	Ordinary kankar lime, Akbarpur quarry.
A. 9	2 of K. L.	1	Ditto ..	Same lime used as in A.8.
A. 10	3 of K. L.	1	Ditto ..	Ditto ditto.
A. 11	1 of K. L.	1	Ditto ..	Ditto ditto.
A. 12	1 of ct. C.	..	3rd May, 1873 ..	Cement C. was used (pieces slightly vitrified).
A. 14	1 of ct. E.	..	10th ditto ..	Ditto E. ditto.
A. 15	1 of ct. F.	..	13th ditto ..	Ditto F. ditto.
B. 1	1 of ct. A.	..	8th April, 1873 ..	Ditto A. ditto.
B. 2	1 of ct. B.	..	11th ditto ..	Ditto B. ditto.
C.	1 of ct. 14.	..	23rd March, 1873	Ditto 14 ditto.
D. 1	1 of K. L.,	..	2nd May, 1873, ..	Ordinary kankar lime, Baloni quarry.
D. 2	3 of K. L,,	1	Ditto, ..	Same lime used as in D. 1.
D. 3	1 of K. L.,	..	30th ditto, ..	Ordinary kankar lime, Baloni quarry.
D. 4	4 of K. L.,	1	Ditto, ..	Same lime used as in D. 3.
D. 5	1 of K. L,	..	14th August, 1873	Ordinary kankar lime, Baloni quarry.
G.	1 of ct. G.,	..	12th October, 1873	Cement G. was used.
H.	1 of ct. H.,	..	13th ditto, ..	Ditto H. ditto.
I.	1 of ct. I.,	..	15th August, 1873	Ditto I. ditto.
I i.	1 of ct. I. i.,	..	13th October, 1873	Ditto I i ditto.
J.	1 of ct. J.,	..	6th August, 1873	Ditto J. ditto.
K.	1 of ct. K.,	..	8th ditto, ..	Ditto K. ditto.
L.	1 of ct. L.,	..	17th ditto, ..	Ditto L. ditto.
M.	1 of ct. M.,	..	12th October, 1873	Ditto M. ditto.
M. 1	1 of K. L.,	..	11th April, 1873	Ordinary kankar lime, Muhammadpur quarry.
M. 2	3 of K. L.,	1	Ditto, ..	Same lime used as in M. 1.
M. 3	4 of K. L.,	1	Ditto, ..	Ditto ditto.
M. 4	1 of K. L.,	..	12th ditto, ..	Ordinary kankar lime, Muhammadpur quarry.
M. 5	5 of K. L.,	1	Ditto, ..	Same lime used as in M. 4.
M. 6	6 of K. L.,	1	14th ditto, ..	Kankar lime used, Muhammadpur quarry.
M. 7	1 of K. L.,	..	15th ditto, ..	Ordinary kankar lime, Muhammadpur quarry.
M. 8	2 of K. L.,	1	Ditto, ..	Same lime used as in M. 7.

Table showing date of manufacture and ingredients used in the Sample Bricks and Mortar—(Concluded).

Distinguishing mark of sample.	Ingredients.		Date of manufacture.	Remarks.
	Parts of lime or cement measured in paste.	Parts of surkhi measured dry.		
M. 9	1 of K. L.,	..	17th April, 1873,	Ordinary kankar lime, Muhammadpur quarry.
M. 10	4 of K. L.,	1	Ditto, ..	Same lime used as in M. 9.
M. 11	3 of K. L.,	1	Ditto, ..	Ditto ditto.
M. 12	1 of K. L.,	1	Ditto, ..	Ditto ditto.
N.	1 of ct. N.,	..	10th October, 1873	Cement N. was used.
O.	1 of ct. O.,	..	9th ditto, ..	Ditto O. ditto.
P. 1	1 of K. L.,	..	16th May, 1873,..	Ordinary kankar lime, Pahokurpur quarry (*all* vitrified and underburnt pieces were rejected).
P. 2	4 of K. L.,	1	10th ditto, ..	Same lime used as in P. 5.
P. 3	5 of K. L.,	1	Ditto, ..	Ditto ditto.
P. 4	3 of K. L.,	1	16th ditto, ..	Ditto ditto P. 1.
P. 5	1 of K. L.,	..	10th ditto, ..	Ordinary kankar lime, Pahokurpur quarry.
P. 6	6 of K. L.,	1	16th ditto, ..	Same lime used as in P. 1.
P. 7	2 of K. L.,	1	Ditto, ..	Ditto ditto.
P. 8	1 of K. L.,	1	Ditto, ..	Ditto ditto.
P. 9	1 of K. L.,	..	17th ditto, ..	Ordinary kankar lime, Pahokurpur quarry, N.B.
P. 10	4 of K. L.,	1	Ditto, ..	Same lime used as in P. 9.
P. 11	3 of K. L.,	1	Ditto, ..	Ditto ditto.
P. 12	2 of K. L.,	1	Ditto, ..	Ditto ditto.
R.	1 of ct. R.,	..	8th October, 1873	Cement R. was used.
T.	1 of ct. T.,	..	12th ditto, ..	Ditto T. ditto.
U.	1 of ct. U.,	..	21st Sept., 1873,	Ditto U. ditto.
V. v	1 of ct. V. v.	..	13th ditto, ..	Ditto V. v. ditto.
V. 5	1 of ct. V.5.,	..	17th ditto, ..	Ditto V. 5. ditto.
W.	1 of ct. W.,	..	5th ditto, ..	Ditto W. ditto.
X. x	1 of ct. X. x.,	..	18th ditto, ..	Ditto X. x. ditto.
II.	1 of ct. II.,	..	31st August, 1873	Ditto II. ditto.
IV.	1 of ct. IV.,	..	5th Sept., 1873,..	Ditto IV. ditto.

Table C.

Table showing composition of Artificial Cements.

Class of cement.	Parts of kankar powder not calcined.	Parts of calcined kankar powder rather underburnt.	Parts of clay.	Parts of quicklime.	Parts of fat carbonite of lime.	Remarks.
No. 14	4	..	1	..	..	Muhammadpur kankar and Narora clay.
A. ..	5	..	1	..	..	Quarry not known.
B. ..	6	..	1	..	..	Quarry not known.

Table showing composition of Artificial Cements—(Concluded).

Class of cement.	Parts of kankar powder not calcined.	Parts of calcined kankar powder rather under burnt.	Parts of clay.	Parts of quicklime.	Parts of fat carbonate of lime.	REMARKS.
C. ..	6	..	1	..	..	Akburpur kankar and ordinary clay.
E. ..	4	..	1	..	..	Ditto ditto
F. ..	1	..	..	..	..	Akbarpur kankar ground fine.
G. ..	..	5	1	..	..	Pahokurpur kankar and ordinary clay.
H. ..	5	..	1	..	..	Muhammadpur kankar and ordinary clay.
I. ..	..	5	..	1	..	Pahokurpur kankar and bazar lime.
J. ..	5	..	..	1	..	Muhammadpur kankar and bazar lime.
K. ..	4	..	..	1	..	Ditto ditto.
L. ..	*4	..	1	..	..	Muhammadpur kankar and ordinary clay.
M. ..	1	..	..	..	..	Ditto ground fine.
N. ..	5	..	..	1	..	Pahokurpur kankar and bazar lime.
O. ..	5	..	1	..	..	Ditto and ordinary clay.
R. ..	4	..	..	1	..	Ditto and bazar lime.
T. ..	7	2	..	..	..	Ditto ground fine.
U. ..	4	..	1	..	..	Baloni kankar and ordinary clay.
V. ..	4	..	..	1	..	Ditto and bazar lime.
W. ..	5	..	1	..	..	Ditto and ordinary clay.
X. ..	1	..	..	..	..	Ditto ground fine.
II. ..	6	..	..	..	1	Muhammadpur kankar.
IV...	7	..	..	..	1	Ditto.

Letter from Exec. Engineer, Narora Division, Lower Ganges Canal.—Dated Narora, the 2nd December, 1874.

I have the honor to forward a Table showing the results of breaking down the briquettes made by Mr. King; also, for comparison, some results obtained from the common lime used here.

Mr. King has done us a great service in leading the way in experimenting, but the results show that it is scarcely worth while to use the more tedious processes of burning when the ordinary one gives results so nearly approaching those so obtained, and at a considerably less age.

The mixtures marked A.3 and K. are the only ones which exceed in any marked manner the ordinary lime.

I regret extremely that many of the specimens were accidentally broken: a good many were received so, and many more were broken during the long time we had to wait for means of breaking them properly.

TABLE D.

MR. KING'S EXPERIMENTS.

Table showing date of manufacture and ingredients used in the Sample Bricks of Mortar.

Distinguishing mark of sample.	Parts of lime or cement measured in paste.	Parts of surkhi measured dry.	Date of manufacture.	Date of breaking.	Age.	Breaking weight	Area of section.	Breaking weight per square inch of each sup. ft.	Mean breaking weight per square inch.	REMARKS.
					Days.					
A. 1,	1 of K. L.	1	22nd March, 1873,	12th Sept., 1874,	538	294	2·15	136	..	
A. 1,	Ditto	..	..	..	..	349	1·96	173	154	
A. 3,	4	1	28th ditto,	12th Sept., 1874,	532	580	2 40	241	241	
A. 4,	..	..	28th March, 1874,	..	..	373	3·00	124	..	
A. 4,	5 of K. L.	1	..	..	..	297	3·00	99	..	
A. 4,	..	..	..	..	..	152	2·40	63	95	
A. 5,	..	..	..	15th Sept., 1874,	..	296	2·40	123	..	
A. 5,	..	..	..	27th August, 1874,	..	223	2·25	99	..	
A. 5,	1 of K. L.	..	29th March, 1873,	Ditto,	516	193	2·40	80	..	
A. 5,	..	..	..	..	..	263	2·55	103	..	
A. 5,	..	..	..	..	..	232	2·60	89	99	
A. 6,	3 of K. L.	1	29th March, 1873,	15th Sept., 1874,	534	447	2 25	199	..	Broke on a large section, not on the neck.
A. 7,	..	..	Ditto,	12th ditto,	531	576	2·56	225	..	
A. 7,	..	..	..	Ditto,	..	285	2·25	127	..	Did not break across.
A. 7,	4 of K. L.	1	29th March, 1878,	27th ditto,	516	..	..	..	..	Accidentally broken in handling.
A. 7,	..	..	..	..	..	34	2·25	..	..	Large flaw omitted in mean.
A. 7,	..	..	..	..	..	538	2·85	189	180	Broke in hand.
A. 8,	1 of K. L.	..	30th March, 1873,	27th August, 1874,	515	335	2·25	149	..	Broke in head on A = 3·32.
A. 8,	..	..	..	..	..	321	2·70	119	134	
A. 9,	..	..	..	..	..	291	2·40	121	..	Broke through the head.
A. 9,	2 of K. L.	1	30th March, 1873,	..	..	589	2·25	128	124	

Table showing date of manufacture and ingredients used in the Sample Bricks of Mortar.—(Continued).

Distinguishing mark of sample.	Parts of lime or cement measured in paste.	Parts of sand measured dry.	Date of manufacture.	Date of breaking.	Age.	Breaking weight.	Area of section.	Breaking weight per square inch of each sqr. ft.	Mean breaking weight per square inch.	REMARKS.
					Days.					
A. 10,	..	..	..	..	..	319	2·25	141	..	
A. 10,	3 of K. L.	1	30th March, 1873,	..	..	434	2·55	179	..	
A. 10,	..	..	..	..	..	226	2·40	94	138	
A. 11,	..	..	..	..	..	295	2·25	131	..	Broke high up.
A. 11,	1 of K. L.	1	30th March, 1873,	15th Sept., 1874,	533	124	2·25	56	93	
A. 12,	1 of ct. C.	..	3rd May, 1873, ..	Ditto, ..	500	230	2 25	102	..	
A. 15,	1 of ct. P.	..	13th ditto, ..	27th August, 1874,	502	353	2·75	128	..	
D. 5,	1 of K. L.	..	14th August, 1873,	Ditto, ..	318	105	2·25	47	..	Broke through head.
G.	1 of ct. G.	..	12th October, 1873,	15th Sept., 1874,	338	105	2·25	47	..	Ditto. ditto.
J.	..	..	..	..	..	418	2·30	182	..	
J.	..	..	..	..	..	400	2 25	178	..	
J.	1 of ct. J.	..	6th August, 1873,	15th Sept., 1874,	375	297	2·25	132	..	
J.	..	..	..	..	..	374	2·40	156	..	Broke fair.
J.	..	..	..	..	..	343	2·25	152	100	
K.	..	..	..	..	..	408	2·25	181	..	
K.	..	..	..	..	..	620	2·25	275	..	
K.	1 of ct. K.	..	8th August, 1873,	15th Sept., 1874,	373	377	2·25	167	..	Broke fair.
K.	..	..	..	..	..	384	2·40	160	..	Bubble ¾ × ¾.
K.	..	..	..	..	..	390	2·30	169	190	
					Broke in two places with 1 cwt.					
M. 2,	3 of K. L.	1	11th April, 1873,	15th Sept., 1874,	532	..	2·25	..	..	Weight put on by mistake.
M. 3,	4 of K. L.	1	12th ditto, ..	Ditto,	532	51	2·25	23	..	
M. 4,	1 of K. L.	..	Ditto, ..	Ditto,	531	79	2·25	35	..	

							Days.					
							Broke in two places with 1 cwt.					
M. 6,	6 of	K. L,	1	14th ditto ..		Ditto, ..	529	..	..	..	..	Weight put on by mistake.
T.	1 of	ct. T,	..	12 October, 1873,		Ditto, ..	338	168	2·25	72	..	
V.	..		..	..		Ditto, ..	..	220	2·89	76	..	
V.	1 of	ct. V.V,	..	13th Sept., 1873,		Ditto, ..	367	94	2·25	42	59	
V. 5,	1 of	ct, V.5,	..	..		Ditto, ..	..	168	2·40	70	..	
X.	..		..	..		Ditto, ..	..	363	2·40	151	..	
X.	..		..	..		Ditto, ..	..	212	2·25	94	122	
X. x.	1 of	ct. X. x.	..	13th Sept., 1873,		Ditto, ..	367	246	2·26	109	..	
I.	2	1		12th April, 1873,	10th	ditto, ..	151	469	3·40	138	..	Did not break at the neck.
II.	2	1		26th ditto, ..	15th	ditto, ..	142	582	3·96	147	..	
III.	2	1		28th ditto, ..		Ditto, ..	150	419	3·40	123	136	
	2	1		20th March, 1873,	10th	ditto, ..	174	276	2·10	131	..	Mortar in use.
	2	1	Bailoni.	22nd ditto, ..		Ditto, ..	172	240	2·10	114	122·5	Ditto.
	2	1		19th Febry., 1873,	12th	ditto, ..	205	148	1·95	71	..	Mortar.

Note by M. KING Esq., *Asst. Engineer, &c.—Dated the 18th Dec.* 1874.

It is to be regretted that so many specimens were accidentally broken, and that Major Helsham Jones had to wait so long for means to test the briquettes properly. His Table B. shows the results obtained in breaking 51 specimens only, whereas about 200 sound briquettes were despatched from Aligarh.

General results deduced from experiments on such a limited scale are seldom reliable and often contradictory. Take, for instance, the specimens marked A.1, A.3, A.4 to A.11, with were manufactured from kankar obtained from the Akbarpur quarry, material supposed at that time to be only fit for road metal. Assuming the ages of the specimens to be the same in all cases, the following analysis shows the average results obtained by the admixture of a constantly increasing proportion of surkhi :—

Kankar from Akbarpur Quarry.

Number of specimens tested.	Parts of kankar lime measured in paste.	Parts of surkhi measured in powder.	Average breaking weight in lbs. per square inch.
7	1	0	109
3	5	1	95
4	4	1	195
4	3	1	153
2	2	1	124
4	1	1	124

The above analysis (if the results may be relied on) would show that four parts of kankar lime in paste to one of surkhi in powder is the combination best adapted to the stone obtained from the Akbarpur quarry. But comparison of facts deduced from the few experiments tabulated above leads to such contradictory results, that it would be unwise to arrive at any definite conclusion in regard to the nature of the limestone furnished by the quarry. If, for example, a briquette of pure lime breaks with 109 lbs. to the square inch, and a sample composed of four parts of the same lime to one of surkhi is able to stand a strain of nearly 195 lbs. to the square inch, it is hard to explain why the tenacity of an intermediate mixture (five of lime to one of surkhi) should be represented by 95 lbs. only. In the same way, if one of lime to one of surkhi breaks with 124 lbs., and four of lime to one of surkhi is able to resist a strain of nearly 195 lbs., the natural inference in regard to an admixture of two of lime

to one of surkhi is that 163 lbs. = 124 lbs. + $\frac{5}{9}$ (195 − 124) lbs., would represent the tenacity of such a briquette.

These contradictions clearly point to the necessity of experimenting on a much greater number of specimens if it is desired to arrive at tolerably correct results.

A noteworthy fact established by these experiments is the high tenacity of mortar carefully prepared from the kankar limestone found so abundantly in the North-Western Provinces: samples A.3 and A.7 (four of kankar lime to one of surkhi) broke respectively with 241 and 225 lbs. to the square inch. But the best result of all was given by one of the specimens marked K; this briquette represented an artificial cement, formed by mixing four parts of kankar from the Muhammadpur quarry with one part of fat lime. The kankar was reduced to an impalpable powder, and, after careful admixture with fat lime, was made into balls and calcined thoroughly in a furnace, with charcoal as fuel.

The two béton blocks mentioned in my Note of the 2nd May, 1873, were removed from the Someyra Falls after an immersion of nearly six months. They showed no signs of wear, and the trial clearly proved, if indeed there were any doubts on the subject, that blocks of concrete carefully manufactured with ordinary kankar mortar are capable of resisting the action to which the stone in the talus of the Narora weir will be subjected.

M. K.

No. CLXXIV.

MODIFICATIONS OF BULL'S PATENT ANNULAR KILN.

[*Vide* Plate XLVII.]

Communicated by H. BULL, ESQ., *Asst. Engineer, P. W.*

THE modifications of Bull's Patent Annular Kiln, as explained in the following Article and Drawings are, it is believed, worth consideration to any one interested in Brick and Tile Burning. They were worked out during a season's burning operations at Agra. They consist of, and their advantages are:—

1*st.*—The kiln being simply two brick wall rings, without any kind of flue, rouse, or fire bars. This, whilst reducing the cost of the kiln from Rs. 500 to Rs. 300, or Rs. 350, increases its capacity of out-turning bricks from 4 to 5, or 5½ lakhs per month, 25 lakhs of bricks,—or rather 21½ lakhs of bricks and 1¾ lakhs of 15-inch Allahabad Tiles (the tiles having taken up the space of 3½ lakhs of bricks),—having been the actual out-turn in five months, from the middle of January to the middle of June. Or, if a larger out-turn be not required than is given by the original plan, the cost of kiln is still further reduced by about Rs. 50; height of kiln being reduced. In the original plan, where fire bars set in a raised platform are used, the burning ashes or charcoal, which are in my opinion the very essence of heat, drop through the bars into the trough below and do little or no duty; there is no loss of this kind in the altered form, which is in accordance with the well known fact that wood, unlike coal, burns as well, if not better, on a flat surface without any openings below, than in a grate: witness the old fashioned fire-places at home for burning logs.

It will be readily allowed that the smaller the surface of the walls, and

the top and bottom of the kiln, are in proportion to the number of bricks contained, the smaller the amount of fuel wasted in heating these surfaces. In the original plan the bricks were loaded only 5 feet high, the kiln was only 12 feet wide, the total area of surface per foot run being $2 \times (5 + 12) = 34$ square feet, the number of bricks contained in one flue, or from the centre of one flue to the centre of the next ($4\frac{1}{4}$ feet), being 2,400. In the new plan the surface is $2 \times (15 + 8) = 46$, the number of bricks 4,000. The proportion in former case being $4\frac{1}{4}$ square feet of surface to 72 bricks, in latter $4\frac{1}{4}$ to 87 bricks, or 1 square foot of surface to 17, and $20\frac{1}{2}$ bricks, respectively.

2nd.—The arrangement of flue space for the chimney:—

As the heat travels nearly horizontally, the flue space in the body of the kiln should theoretically be the same as in the base of the chimney. It is not easy to work this out exactly, but I have endeavoured to arrange for this as nearly as possible. In the old plan the flue space in body of kiln was that contained between the concentric walls, which were $2\frac{1}{2}$ to 4 inches apart; the total area being this width × number of spaces between concentric walls × height of loading—the last being 5 feet. At the chimney the covering bricks were left out across the kiln for a length of $1\frac{1}{2}$ feet longitudinally, so that the area of flue space at base of chimney was, this same width × the same number of spaces between concentric walls, × $1\frac{1}{2}$ *feet* only, or less than one-third of former. In the new plan, at the position of chimney, (*see* longitudinal section,) a space is left in the body of the kiln 1 foot longitudinally, extending (with exception of one or two walls left for strength) right across the kiln. At the level of the third layer from the top, the area of the chimney flue is $\{15' - (2 \times 9\frac{1}{2}'')\} \times 1$ or about $13\frac{1}{2}$ square feet. If the cross and longitudinal sections be examined in conjunction, it will be seen that this space is further increased by the arrangement of the two top layers, and the width of the chimney being increased. The increase is about 6 square feet, making a total of $19\frac{1}{2}$ square feet; that in the body of the kiln being $2\frac{1}{2}''$ (wide) × 6′ 5″ (high) × 16 (number of spaces) (deducting the depth of binder bricks which run across the kiln), or 22 square feet.

I need hardly reason on the advantage of this arrangement, for it is apparent that if there be insufficient chimney space, it is impossible for the back heat to come forward. I argued in this manner to myself, that

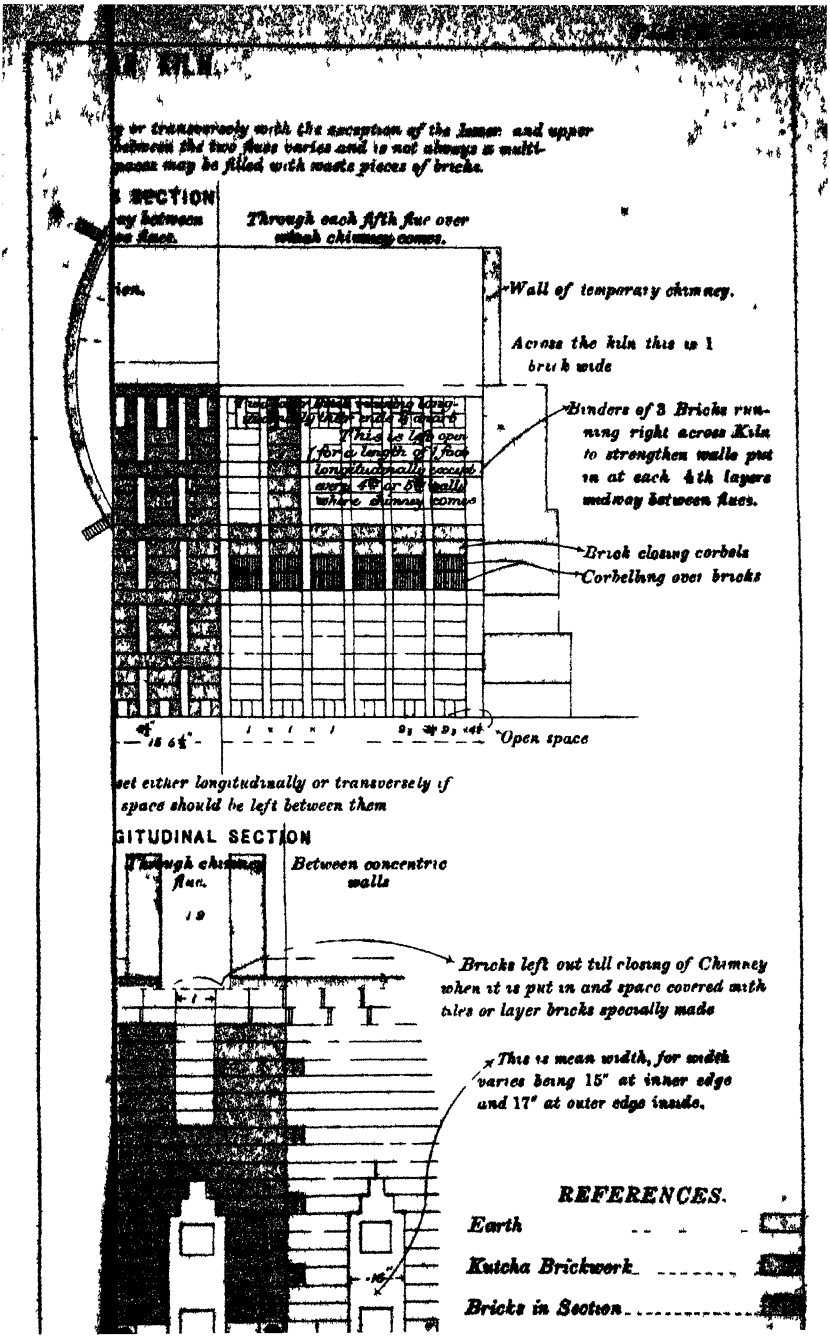
lakhs were burnt with 700 to 750 maunds, and the average of the 25 lakhs (a large proportion of which were burnt before the improvements were made) was 950 maunds of 4 cubic feet. On comparing this quantity with the quantity used in an ordinary flame kiln, it should be borne in mind that in the latter the fire doors are so large, that pieces weighing 1½ or 2 maunds may be thrown in, whereas in the Annular Kiln the largest piece cannot weigh more than 20 or 25 lbs. When fuel is purchased by measure, as it generally is, this makes a great difference. Supposing fuel for the Annular Kiln took 4 feet to the maund, that for the ordinary flame would probably take 3 feet only.

I might add, that one of the immediate results of the new arrangement for chimney flues was, that both the ash and firing flues could be kept almost entirely closed, the draught being all drawn from behind, in of course a heated state; using heated instead of cold air for the combustion must add considerably to the saving of fuel.

3*rd*. The arrangement for loading the upper layers:—

This will be easily understood from the Plate. It has generally, I believe been found difficult to get the upper two layers thoroughly burnt. By loading in the manner shown in the Sections, the difficulty is entirely overcome, as a much larger amount of free surface is there exposed to the action of the heat.

I would further recommend three earthen pipes being placed at top of the kiln in a transverse line midway between two flues directly above the binder bricks, one at each edge of kiln, and one in middle, so situated


...N KILN.
...or transversely with the exception of the lower and upper ...between the two flues varies and is not always a multi... ...space may be filled with waste pieces of bricks.
...SECTION
...ay between ...ue flues.
Through each fifth flue over which chimney comes.
...ion.
Wall of temporary chimney.
Across the kiln this is 1 brick wide
Binders of 3 Bricks running right across Kiln to strengthen walls put in at each 4th layers midway between flues.
Brick closing corbels
Corbelling over bricks
Open space
...set either longitudinally or transversely if ...space should be left between them
...GITUDINAL SECTION
Through chimney flue.
Between concentric walls
Bricks left out till closing of Chimney when it is put in and space covered with tiles or layer bricks specially made
This is mean width, for width varies being 15" at inner edge and 17" at outer edge inside.
REFERENCES.
Earth
Kutcha Brickwork
Bricks in Section

that charcoal can be dropped down on the binder bricks. I recommend this, as these are the places where the bricks tend to remain underburnt. Charcoal might be dropped down say every half hour, and the pipe covered with a cake of clay, or any kind of burnt clay covering. At commencing operations, the percentage of 1st class bricks was not high. I had had little experience in brick burning. I had great difficulty in gauging the burning (which was frequently carried too far) as the Agra clay scarcely shrinks in burning; and there is, moreover, a large amount of bujrí contained in it, which causes many bricks to break. For the last three months, however, it rose considerably. The actual out-turn in April, May and June was 9,72,000 first class pucka bricks only, or 3,24,000 a month. One-fifth of the space in the kiln was taken up for tiles, besides which about 4,20,000 bricks were loaded per month. This gives a percentage of 77 on the bricks only; 2½ per cent. of out-turn was distorted, 2½ pucka or vitrified bats, 8 per cent. second class, and the rest peela: Rs. 2-2 was the rate paid for labor, preparing ground, digging, pugging, moulding, loading, firing, and unloading, calculated on first and second class out-turn only. The tiles were put into the best part of the kiln, and turned out exceedingly well. Of 1,72,000 loaded, 1,63,000 really serviceable tiles were out-turned.

As regards the working. A wall, say 1½ thick, is built across the kiln either midway between two flues, or taking the place of what would be the bricks at one side of the flue, as shown in plan, the corbels being built in the wall. It is useless loading the bricks to full height at starting, on account of the heat travelling horizontally forwards. The wall should therefore be built to a height of about 3 bricks above top of corbels, and the bricks stepped upwards till over the middle of second flue they are loaded full height. When loading, a line must be stretched across kiln, with the positions of the concentric walls marked on it. The flue is 15 inches wide at inner wall, and 17 inches wide at outer wall, so that if the line be set 3½ inches from the 9 inches square ash-flue on inner side, and 4½ inches on outer, the correct width of flue will be arrived at. The line may be dispensed with by making a brick flooring, the bricks being set flat, except where the kutcha brick walls are to be loaded, and there they are set on edge. The latter will, of course, be an inch or two above the remaining part, and serve as permanent guides for the loading. Bats or any refuse will do for the flat brick part, but

whole bricks, either peela or kutcha, should be used for the brick-on-edge. The new bricks are loaded on these low bricks-on-edge walls, which latter are coincident in area with the walls to be built above, as shown in plan. It may be thought that the flat bricks might be dispensed with, and the cost lessened by laying the remaining flat, but it will be found that without something to keep the latter in their places they will be kicked up in the operations of loading and unloading. The arrangement is not absolutely necessary, all that is required being a level floor with the earth well rammed, but I think the convenience is well worth the extra cost of say Rs. 50. The loading is carried on as shown in plan for say 10 flues, when the space for chimney should be left. The bricks may be loaded with their lengths longitudinally or transversely, whichever is most convenient. In the former case, as three bricks' widths measure only $8\frac{5}{8}$ inches, and the length of a brick is $9\frac{1}{2}$ inches, there will be sufficient space between them for the heated air to circulate. In the latter case they should be set $\frac{1}{2}$ or $\frac{3}{8}$-inch apart. In the cross wall built at commencement, two or three air holes, 9 inches square, should be allowed at bottom, to be built up and plastered over in such a way, that they may afterwards be conveniently opened again. The loading having been completed to ten flues with the exception of the earth on top, firing may be commenced *easily*, in the first flue; after six hours, a second flue may be fired, and the 6-inch layer of earth placed over first flue; after six more hours, a third flue may be fired, and earth placed over two more flues; and so on, a flue being opened every six hours, till six, seven, or eight are being fired, earth being placed over two flues at a time till the chimney is reached. The earth may after this be placed as the bricks are loaded. The space for chimney should after commencement be left at every fifth flue, this rule being adhered to—that the firing is never nearer than three flues to the chimney. When it has reached within this distance the chimney should be closed, by first replacing the bricks left out as shown in plan, and then spanning the remaining space with refuse 15 inches tiles or bricks made specially for the purpose. The loading should at the time of closing the chimney have proceeded so far, that a second chimney may be built up; in fact it is a good rule to always have two chimneys, or rather chimney spaces, ready beyond the one actually in use.

Nine flues is the utmost that may economically be fired at one time, and of those being fired;—this rule should be adhered to in the firing,

that never *more than* three foremost flues are fired *hard*, the rest being fired easily, the last opened very easily indeed, with only chips or light branches. Seven flues is the number I should recommend to be fired at once, and in this case the fire in flue No. 1 should be pushed when the sixth is opened, and No. 2 when the seventh is opened, and so on, two flues only being fired hard. In from 30 to 40 hours the bricks in first flue will be pucka. No fixed rule can be given for deciding on this as some clays shrink much, some scarcely at all, some will be found fully burnt when they have arrived at a full white heat (which may be ascertained by making holes in the covering), some have to be kept at such a heat for a length of time, so at starting operations, the closing of the flues must be considered purely experimental. Careful note should be made of the conditions under which each flue is closed, and after a month or six weeks a decided opinion may be formed as to when a flue should be closed.

I must define what I mean by firing hard and firing easily. By firing hard, I mean to throw in as much fuel as will burn *freely*, the object to be aimed at, being the consumption of the largest amount of fuel with the smallest accumulation of charcoal. Charcoal will collect to some extent, but that is useful, as it can be easily distributed so as to give an even heat right across the kiln, and if the burning logs can also be arranged in this manner the firing is as near perfection as it can be. Throwing logs over others only half burnt has a pernicious effect, as tending to cause charcoal to accumulate too largely. It should be remembered throughout the operation of firing that the side walls tend greatly by their mass to take the heat from the bricks set nearest them. It will, therefore be found a good plan to always have a good log burning, half in the hard-fired flue itself, and half hanging over the wall; even after closing a flue it may be found necessary to put a log in this position, to be succeeded by others as each is burnt out. Unless the side walls at their inner surfaces be raised to the same, or nearly the same, heat as the bricks themselves, the bricks nearest them are sure to be underburnt, and the operator must make up his mind to sacrifice a large amount of fuel for this.

By firing easily, I mean distributing the fuel sparingly, to try and get no charcoal whatever, the lightest pieces being used for the most newly fired, the thickness and size in the rest graduating from this to where hard firing is being carried on. The closer these rules are attended to the less will be the consumption of fuel. One inch iron pokers, 10 or 12 feet

long, with a bend at the end, of 3 or 4 inches, should be used in distributing the fuel. For starting a new flue, a scoop, a foot long and of segmental or semi-circular section with a chord of 4 or 5 inches, should be used to draw some of the burning charcoal from one of the hard-fired flues, and to place in the one just opened. The scoop is rivetted to a rod iron handle, $\frac{3}{4}$-inch diameter and 4 or 5 feet long. On top of the charcoal some light pieces should be thrown till the fire is well lighted. As a flue is closed another should be opened.

The flues, both ash and firing, are closed with an earthen dummy, 9 inches square tapering to $8\frac{1}{2}$ inches square, 3 inches thick, with a hole in the middle, $1\frac{1}{2}$ or 2 inches in diameter, to allow of examining the fire.

As regards opening the ash flues for draught, this must be decided on by circumstances. At starting the whole of the ash openings to the flues being fired will probably have to be kept partly open. When five flues have been closed the openings in the cross wall, mentioned above, should be made, small at first and increased in size gradually as the firing continues till after ten flues are closed, it will probably be found that the ash openings to the flues being fired may be almost entirely closed, the necessary draught being drawn from the end openings. A good rule after this will be probably to open the tenth ash flue behind the firing and each fifth flue beyond that to the thirtieth flue, beyond which all the ash flues may be opened. When fifty flues have been closed, the firing opening of flue first fired may be opened. The bricks may be taken out as soon as they are cool enough, after having first demolished the cross wall. The layer of earth may be taken from the top of first flue after the fiftieth flue has been closed, and the flat layer of bricks turned on edge so as to allow the bricks to cool. By this plan the number of flues loaded at a time will be—

Burnt bricks cooling, all openings having been made,	5 flues.
Annealing flues, lower openings open here and there,	50 „
Firing,	7 „
Between firing and chimney,	3 „
Loaded beyond chimney,	10 „
Total	70 „

As in the kiln there are 107 flues, the loading and unloading are at least thirty flues apart.

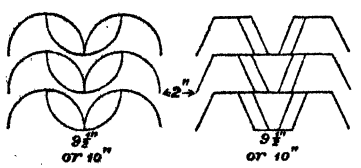
All openings between part firing and chimney should be carefully closed.

Doorways, 2 feet wide, are allowed in outer wall for every ten flues; they are midway between flue opening, and are closed as loading goes on.

If these instructions be carefully attended to, I have no hesitation in saying, that the most inexperienced Engineer can, after a month or six weeks' practice, burn bricks in a satisfactory manner. Once he has found out the rules that suit the particular fuel (almost any kind may be used) and clay there is no need for departing from them, as the system reduces accidents to a minimum.

If tiles are to be burnt, such as the 15-inch Jubbulpore or Allahabad tiles, the best position for them is in the place of the third, fourth and fifth (layers from the top omitting the flat). They should be in concentric rows, the outer ones being at least 4 inches from the sides of the kiln, the other rows at least 2 inches apart. It is of no consequence that the rows of tiles are coincident with those of the bricks, in fact, with the large 12-inch broad flat tiles, this cannot be arranged, with half round or semi-hexagonal tiles, the rows may be coincident with those of the bricks, three being locked together *(Fig. 1)*.

Fig. 1.



The setting of other kinds of tiles must be decided on in each case by the shape. In the place of the kutcha brick chimneys which are made with only loose bricks, I would recommend three or four sheet iron chimneys, 12 feet high, the total area of their bases approximating to the area of the former, and tapering upward to about two-thirds of this area. They should receive two or three coats of tar before use; and to give them a good bearing surface, angle-iron should be rivetted to their bases. I myself latterly used three chimneys of which the section of the base was *(Fig. 2)*, of the top was *(Fig. 3)*; the curved parts were each two whole sheets with their ends rivetted together, and bent to a semi-circular shape, the straight parts consisted of two sheets each cut as in *Fig. 4*, the side pieces being the upper part, the middle the lower part (see *Fig. 5*). These however are hardly large enough. A better arrangement would

Fig. 2.

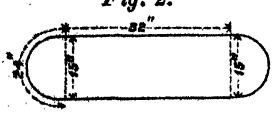
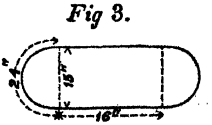


Fig 3.



be I think to have four chimneys, the straight parts the same but the ends segmental, with the chords 20 inches (*Fig.* 6). The four could be comfortably got into the width of the kiln. Their cost would be about Rs. 50 each. They would of course be very heavy, but as the greater part of the weight is at the bases (on account of the taper and angle-irons) there is no difficulty taking them down, removing them, and setting them up again. Three or four layers of bricks should be set round them to keep them steady. When the operations are on a small scale it would hardly pay to use them, but when on a large, as their cost would bear such a very small proportion to the whole cost of the manufacture, it would be advisable to use them. Any arrangement for stopping the draught from coming from the wrong (or brick loading) side of the chimney will increase their effect.

Fig. 4.

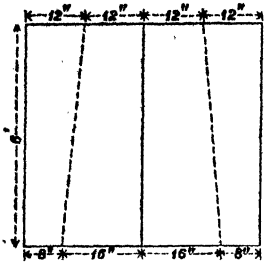


Fig. 5.

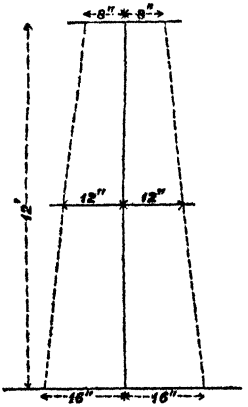
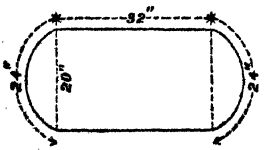


Fig. 6.



The word flue is used,—for the openings to or from the fire,—for the part where the fire actually is,—and (there being no chambers in the kiln), also for a section of the kiln contained between two vertical transverse planes at the centre of two contiguous flues. Thus the expression "bricks" in flue No. 1, means bricks between centre line plane of firing flue No. 1 and firing flue No. 2. The context will I think explain the sense in each case.

H. B.

AGRA,
23rd *September*, 1875.

No. CLXXV.

PUNKAH FOR COOLING RAILWAY CARRIAGES.

[*Vide* Plate XLVIII.].

Designed by Mr. J. G. Cooke, *Locomotive Superintendent, Oude and Rohilkund Railway.*

It will be seen from the Plate that the cooling is effected by means of a punkah or fan kept in constant movement by means of suitable mechanism, which will be understood from the following description:—

The centre of one of the carriage wheels XX is filled up with wood between the spokes so as to form a true surface on the inner side of the wheel against which the friction pulley Q is pressed by its own weight by reason of its axis TT being suspended by the frame UU from two pivots VV. The pulley Q is free to slide on the shaft R, but the shaft and and pulley revolve together. The governor ball S, which is attached to a lever, passing through a slot in the shaft R, is so adjusted by the spiral spring A as to yield to centrifugal force when a certain speed is exceeded, the pulley being actuated by the lever to which the ball is attached, slides on the shaft towards the carriage axle and is thus reduced in speed by coming upon a smaller diameter of the wheel's disc. In this way the speed of the punkah, after the train has attained a certain velocity, is governed and made uniform although the velocity of the train may vary considerably.

Motion is communicated from the shaft R to the hand wheel by a cat-gut band passing round the pulley P, and over the guide pulleys OO and stretching pulley N, the object of the latter being to keep the band tight. The hand wheel B and the pulley which communicates by a strap

with the shaft A together with a small pulley with a V shaped groove are all in one casting and revolve freely on the spindle, the other pulley M which is worked by the catgut band is keyed to the spindle. By means of a simple friction clutch Y attached to the wheel M and working in the V shaped groove, the whole can be made to revolve together or separately, and the hand wheel B can be turned at a greater velocity than the pulley M without removing the pall or clutch Y, which is pressed into the groove by the spring Z, so that the cooly can commence working the punkah by hand as soon as the train slackens speed and before and during the time the train stops; after starting, he has simply to let go the handle, when the friction gear again takes up the work. When the direction of the carriage is changed the friction pall Y requires to be reversed, and the cooly as a matter of course must turn the handle in the opposite direction.

This system has, we believe, been worked with considerable success on the railway above mentioned, but a simpler form has also been introduced there by Mr. Cooke.

The trains on the Oude and Rohilkund Railway are mixed, and seldom require more than one upper class carriage; it was, therefore, necessary to have an attendant to each carriage, and to work the punkahs by hand instead of connecting them with the carriage axle. This has been effected by placing a flywheel and crank at the end of each carriage to be turned by the attendant, the power being transmitted through a connecting rod from the crank to an overhead weighshaft, the shaft passing longitudinally through the carriages sufficiently removed from the centres to clear the roof lamps, swinging punkah, &c. As the lever upon the weighshaft is equal to or longer than the radius of the circle described by the crank, it is made to vibrate as the crank revolves, and this motion is communicated to each punkah by similar levers keyed upon the weighshaft opposite to the punkahs, to which they are connected by a small rod; thus the punkah makes one double stroke for each revolution of the wheel.

J. G. C.

PUNKAH FOR COOLING RAILWAY CARRIAGES.

Fig. 1

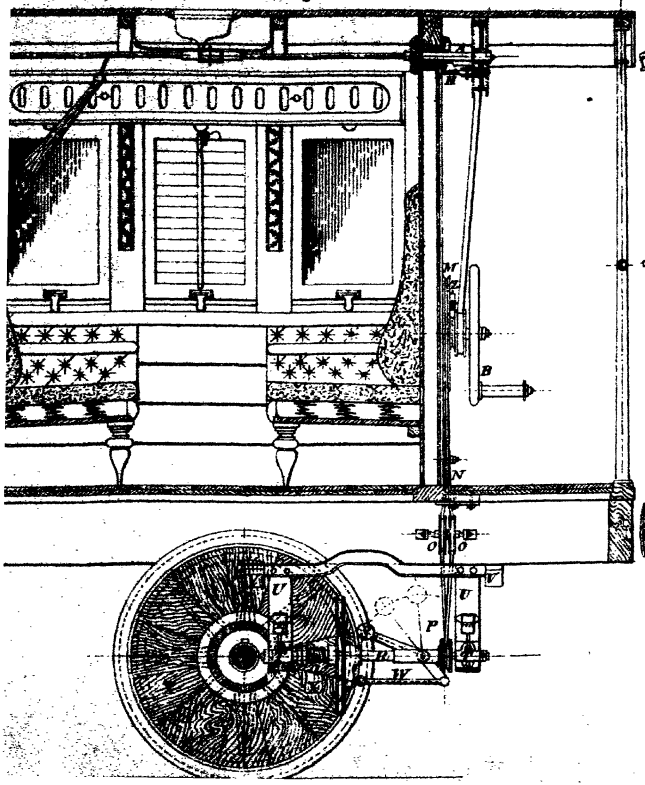


Fig. 2

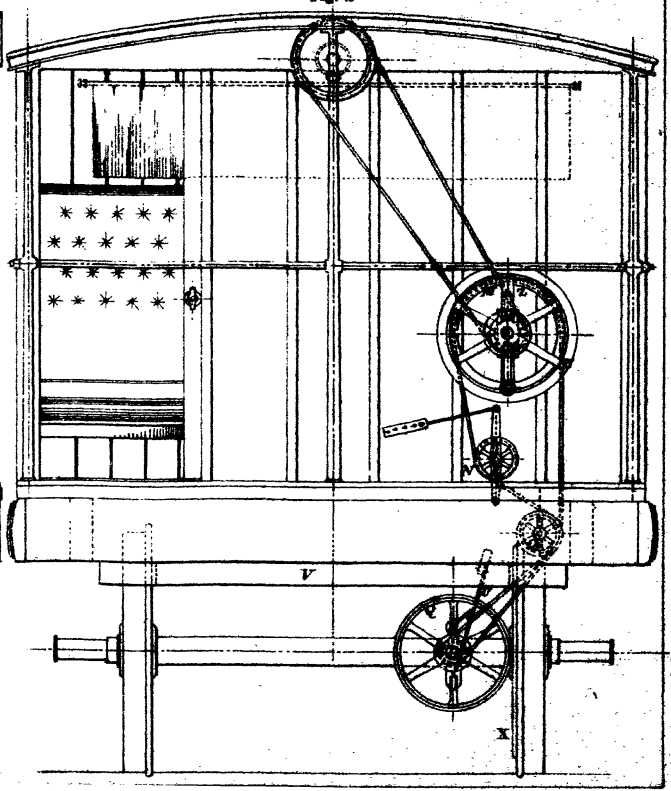


PLATE XLVIII.

No. CLXXVI.

PROTECTIVE RIVER WORKS AT DERA ISMAIL KHAN.

[*Vide* Plates XLIX., L., LI.]

Report by H. GARBETT, ESQ., *Exec. Engineer, on Special duty.—Dated Dera Ismail Khán, 26th November*, 1862.

IN obedience to instructions, I have the honor to submit the following Report on the Indus Division Works, and the results attained in the attempt to change the course of the river.

On arrival I strained every nerve to push on the upper bund (marked A in *Plate* L.) with utmost rapidity, and thus taking advantage of the low state of the river to make some impression on the stream before commencing the cantonment defence spurs. In doing so, I was at first more limited by the number of boats which could be spared without interfering with the river traffic or the proper maintenance of the ferries, than by the paucity of laborers; but at a later period the necessity of cutting and gathering the harvest, and the return of the Povindahs to their mountains, deprived me of the majority of my workmen. The practice, however, of personally seeing that each man received his day's wages for the day's labor, enabled me to secure a small but certain supply for only two and-a-half annas a day, when coolies could scarcely be secured in the station for the higher rate of three annas.

I was enabled to complete a double row of piles nearly across the whole channel, with the exception of gaps left for the passage of boats, by the middle of February, when the works were visited by His Excellency the Commander-in-Chief, and shortly afterwards by the Chief Engineer. On

the completion of the third row, I began to throw in fascines with all the available boats, gradually raising the bund along the whole line to within three feet of the surface of the water, and afterwards completing the same to the height of a foot or so above the water level.

In spite of all the precautions I took, and the speed with which I worked, scouring took place here and there. In places the pent-up stream fairly burst the dam; in others, from the formation of quicksands, an hundred yards or more of the bund, sometimes stakes and all, sometimes only the fascines, would gradually, but too surely, sink before my eyes. The repair of these places was long and difficult, the river working ceaselessly day and night to enlarge them, whilst I had but the daylight to work in; thus, I often found in the morning that the result of several days' hard labor had disappeared during the night. The whole of March and part of April were thus spent in completing, strengthening, and repairing the main and lower portions of the bund, which, starting from two hundred feet from the edge of the sand bank on the right,—left for the navigation, but protected by the prolongation of the upper, the stakes of which only were driven,—stretched to the left bank.

The results of these operations on the river were, that the discharge down the Rodi channel was greatly increased, both by the enlargement of the old heads, and the formation of new ones leading into it; and the decrease of the main stream, which, though still following the Dera channel, was thrown with full force on the left bank, instead of clinging pertinaciously to the right, as heretofore, and threatening Dera with destruction.

The river, which had gradually risen during March, rose more rapidly in April, partly swollen by the unusually heavy fall of rain during that month, and beginning to cover the sand bank on which the upper portion was to run, warned me that it was fully time to complete it. This would have been done, but for the total failure of the old fascine contractors, and the necessity of sending every fascine that could be made to the cantonment defence spurs for their completion and repairs, besides holding a supply in readiness to meet any emergency that might arise. The upper portion was, however, brought within a distance of two hundred yards of the main.

The cantonment spurs were commenced in March under the immediate care of Lieutenant L. D'A. Jackson, R.E., when the upper works had materially told on the stream, which, though deep and sluggish, was still

strong enough to erode the banks. The rapidity with which crash followed crash as the lumps fell in told me too plainly that the banks in their then unprotected state could not resist the violence of the stream, and I scarcely hoped to preserve the little margin remaining between the river and the grave-yard.

Spur B was put in first to secure a shoal which had just formed on its site, and was pushed out for a length of 520 feet. Having to bear the unbroken force of the stream, it required constant attention and repair. It was twice burst through before I put a breakwater in front of it. The breakwater floated capitally for a few days, and then gradually sunk, the branches and sprays of which it was composed collecting and retaining the silt formed a far better protection than the fascines originally thrown in front, as the latter gradually sunk into the soft mud until they left the front row of piles unprotected.

Spur C soon followed. I placed it a little higher up than I otherwise should to give additional security to the grave-yard, which is within one hundred yards of the edge. It was prolonged for a distance of 580 feet, and gave far less trouble than I had anticipated from the great depth of water through which it was carried.

Spur D was continued for a distance of 400 feet, and Spur E for only 130, as the water beyond it was very deep, and I found that it gave efficient protection for some distance below the Commissioner's, which, being the nearest to the river, was the most exposed house in the station.

It was interesting to watch the protective influence of the spurs extending further and further down the bank as they were prolonged into the stream. After completing the slopes, and protecting them with breakwaters, not a lump fell in, though the long extended cracks in the soil showed that many pieces were detached and ready to give way.

The breakwaters afforded efficient protection from the cutting action of the surface water, and completely prevented erosion by the waves or ripples; but not being sufficiently buoyant to float, they required constant attention in adjusting them to the rise and fall of the river. Bamboos, with their large air cells, would doubtless float, but I do not know of any substitute with analogous structure which could be used here.

The floods during the past season were unusually high and severe. The first was at its highest on the 9th of June, three-quarters of which passed through the Rodi channel. The second great flood was at its greatest on

the 9th of July, but the river remained high and swollen for more than a fortnight; half of this I calculated passed through the Rodi channel. During the whole of August the river was flooded, and it only began to subside slowly in September, and only in the beginning of November were the cold weather channels fairly defined.

The first of the two plans which accompany this (*Plate* XLIX.) shows the state of the river in August, and I have marked on it the course taken by the Steamer "*Napier*" on her first trip up the river on the 14th of July. The current then ran so strong that though we left Dera at daylight we did not reach the point where the track terminates till noon. The second plan shows the present state of the river (*Plate* L).

Though the flank of the Khuk Bund has been turned, and the upper portion destroyed, the course of the river has been totally changed, and the old bed near Dera has been so thoroughly silted up that, instead of being within 1000 feet of the Commissioner's house, it is now more than 1500 feet away from it. One crop has already been reaped near the spurs, on the site of what a few months ago was deep water, and the ground has been again ploughed up and sown with grain.

The greater portion of this is at present a mere sand bank rising between four and five feet above the present level of the water, parts are covered with a thick coating of rich mud, in others patches of grass and jungle are springing up; but so certain are the villagers of its all being finally covered with earth, and of its value, that they have long since laid claim to the recovered land,—such confidence has been inspired in the town that house-building, which had been long suspended, has now been vigorously resumed.

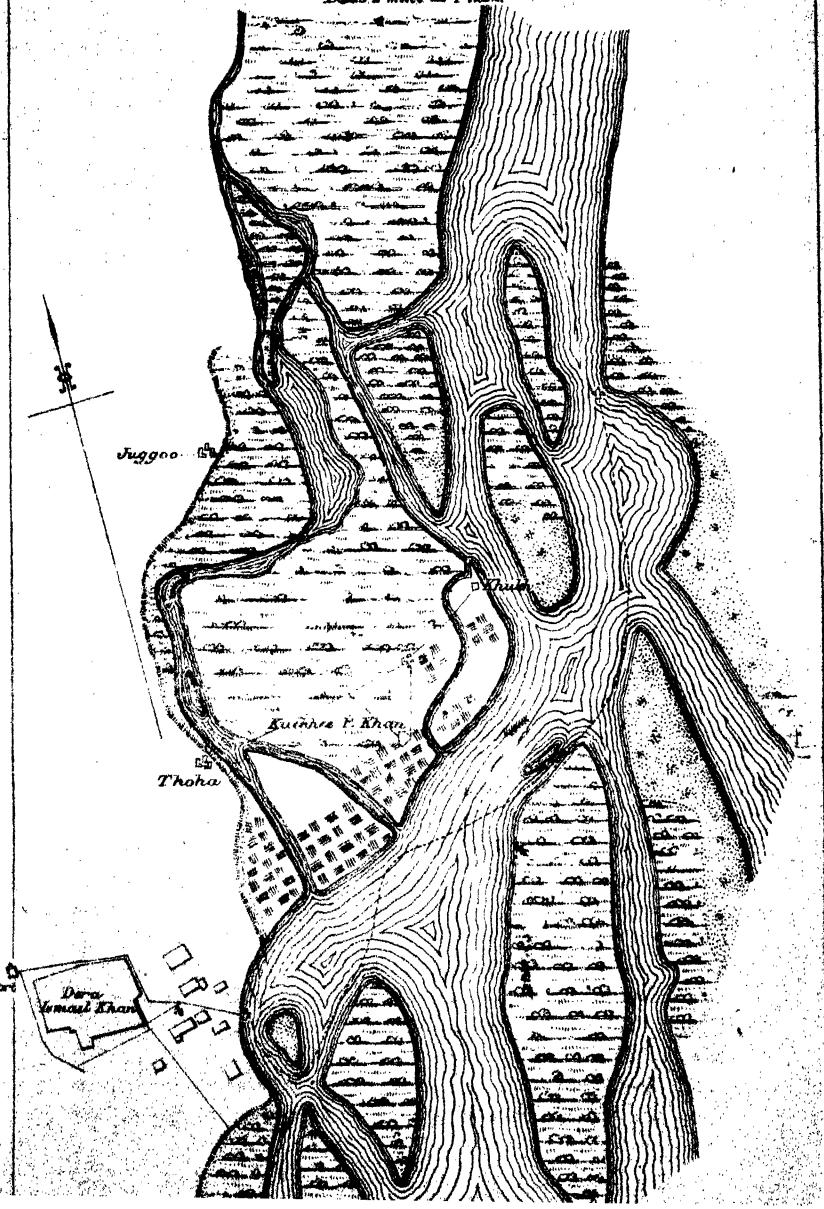
I have carefully examined the course of the river for some twenty-five miles above the station, and for about ten below it. I find that the deep channels in that distance lie now as uniformly on the left, as they formerly did on the right bank, and that the whole course of the river has become straighter, and the boatmen say that it has nearly resumed the line it took some ten or twelve years ago. The heads of the dangerous western nullah have been blocked up with silt, the course of the river generally lying one-and-a-half or two miles away from them, its bed, too, has decreased both in depth and width.

The continued settlement of the spurs near cantonments in comparatively still water, demanding as constant a supply of fascines to keep

PROTECTIVE RIVER WORKS AT DERA ISMAIL KHAN.

AUGUST 1862.

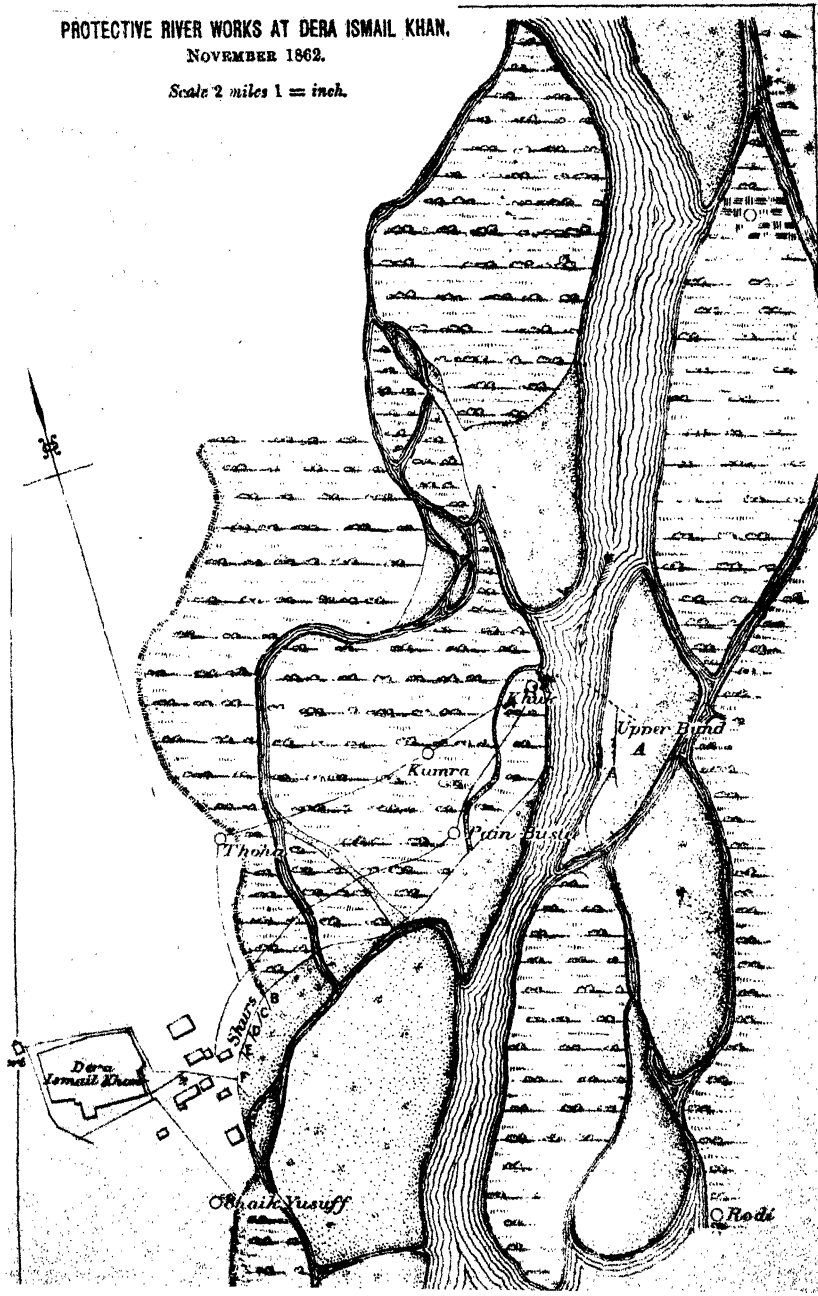
Scale 2 miles = 1 inch.



PROTECTIVE RIVER WORKS AT DERA ISMAIL KHAN.

NOVEMBER 1862.

Scale 2 miles 1 = inch.



them up to their original height, led me to expect that but few traces of the Khuk Bund, which had no such renewal, would be visible on the subsidence of the river. The heads of a few piles appearing here and there above the sand indicate the lines of the main and lower portions. The shoal which has formed in front of it slopes away to the edge of the small stream that follows the former course of the deep channel. Near the village of Rodi, the old channel is upwards of one hundred yards in breadth, and twelve, fourteen, fifteen feet in depth. It continues thus for about two miles above the village, and thence upwards becomes narrower and shallower; but the bed has been immensely enlarged since last year, and appearances lead me to believe that the boatmen are right in thinking that the river is certain to resume that course when it rises next year. The present course being upwards of three miles from the cantonments, I do not recommend anything being done at Khuk.

As far as I have examined the stream the operations have not interfered with the navigability of the river. Channels of five feet in depth being in existence. The steamers cannot, however, approach so close to the cantonments and the town as they have hitherto done during the past season, instead of moving at the end of the road within five hundred yards of the VIth. Punjab Infantry Lines, and three-quarters of a mile from the city, they now stop about two miles from it, and in less than another month will not, I think, be able to come within three. The extra land carriage thus entailed is looked on more as an assurance of safety than an evil.

The drying up of so large a surface close to cantonments has, I believe, slightly increased the amount of fever; and the VIth Punjab Infantry being more exposed to it than the other Corps, has suffered most. To prevent the continuance of this, to ensure the silting up of the small channel, which still clings to the high bank below Spur E, and to save the further loss of land, which being so close to a large town is valuable, I would suggest the prolongation of Spur E, and the construction of two more Spurs F and G, to the length of five hundred feet each. The sand on their sites is hard, and the greater part at present dry; the amount of the estimate for their construction forwarded with this amounts to Rs. 6,328, and includes the sum of Rs. 500 for renewing the breakwaters, of Rs. 150 for continuing the slopes, and also allows for an establishment to attend to the breakwater fascines during the floods.

I have not allowed for stones, and only a small proportion of fascines for repairs, as a large amount of both are in store.

I do not recommend anything for the western nullah. This, so far as I can learn, has always been in existence, and has not increased much of late in size. The great deposit of silt at its mouth, which must impede the flow through it, will naturally tend to rectify any increase there may have been in the past year or two.

It would, I think, be advisable to retain a strip of the newly recovered land, one hundred yards in width, as a plantation, and to sow it with the seeds of the "sísam" tree. The young trees would grow rapidly in the low rich ground, and besides being of ornament and value in a place so destitute of timber, would materially help in keeping off unhealthy exhalations from the river.

Estimate for additional Spurs for the protection of the Cantonment of Dera Ismail Khán for 1862-63.

		Rs.	Rs.
No.			
1,200	Fascines for Spur E, at 6 annas each, ...	450	
2,000	„ „ „ F, „ „	750	
2,000	„ „ „ G, „ „	750	1,950
score.			
370	Bullies, 16′ to 20′, at Rs. 30 per score, ...	555	
1,000	„ 12′ to 18′, at Rs. 25 „	1,250	1,805
l. ft.			
1,370	Of Labor, at Rs. 50 per chain, ...	685	
No.			
5,200	Fascines, carriage of, at Rs. 10 per 100, ...	520	1,205
c. ft.			
1,00,000	Excavation, at Rs. 1-8 per 1,000, ...	150	150
No.			
50	Breakwater fascines, Rs. 10 each, ...	500	
1	Chowkeydar, for 8 months, at Rs. 6, ...	48	
	Establishment for raising Breakwaters for 6 months, at Rs. 15, ...	90	638
			5,748
	Contingencies at 10 per cent.		575
	Grand Total, ...		6,323

H. G.

Report by LIEUT. C. HOSKYNS, R.E., *Offg. Exec. Engineer, Deraját Division, to Supdg. Engineer, 3rd Circle, Punjab.—Dated 12th January,* 1875.

The attached plan (*Plate* LI.) shows the present course of the river. The dotted lines show where the banks of the river were last March. From the map it will be seen that the river, from a point some four or five miles above the village of Khán Khát down to the old mouth of nullah B, in all a distance of some seven miles, has, since last March, cut away the right bank to a considerable extent. The river carried away the village of Kacha Pind, which was situated about where the centre of the bridge-of-boats now is, and has encroached on the village of Khán Khát, a distance of nearly three-quarters of a mile.

The mouth of the nullah B is at present silted up to a thickness of about three or four hundred yards; the remainder of the nullah remains in *statu quo;* should the river cut away the small angle formed by its present course, and that of the nullah B, it would find a ready made channel, which would direct it on the cantonments, and this at present appears to be the chief danger.

The old nallah marked D, through which the main body of water flowed last March, is completely silted up for the whole of its length, and scarce a vestige of it remains.

The arrows on the map show the course of main stream, which has still a tendency to cut away the right bank; at present the river is very low, and but small portions of the bank fall in. The chief force of current is now concentrated on the bank just opposite Khán Khát, which slowly gives way to the action of the water. There are three prominent objects to be attempted—

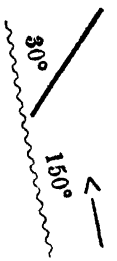
(1). To endeavor to train the cold weather channel back again in a more easterly direction.

(2). To protect the mouth of the nullah B.

(3). To place spurs opposite the cemetery and Commissioner's house so as to protect that bank.

For the training of the cold weather channel the following works are proposed:—Floating spurs are to be placed, as shown in *Plate* LI., at *a* and *b*. These two are only intended as cold weather works, for they are attached to low sand banks, which will be covered when the river rises. These spurs will be constructed as follows: a strong *múnj* cable of about ten

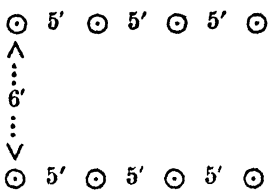
inches in circumference and about 300 feet long will be buoyed on casks, and closed at every twenty feet; when the cable is firmly secured, trees will be fastened to it with short *munj* ropes passing through holes in their butts. Large trees to be placed in deep water, and the smaller ones in shallow. The direction of these floating spurs with that of the current will make an angle of about 150°.



These works will not be expensive; for when the river rises considerably, or when they are having no more effect on the current, the trees, barrels and cable can be taken away on boats and used for the other permanent spurs.

The spurs at 3 and 4 will consist of trees thrown in in a line, each tree being anchored. This work will be continued until the structure rises up to the level of the bank.

As trees are not very abundant, the two spurs 2 and 3 will be made of piles driven in at intervals of five feet, in two rows six feet apart; fascines, six of which will be lashed together to form a small raft, will be thrown



in between. The water here is not more than seven feet in depth, so that piles of eighteen to twenty feet in height will be long enough.

As before stated, the chief object of these two spurs will be to defend the mouth of the nullah B.

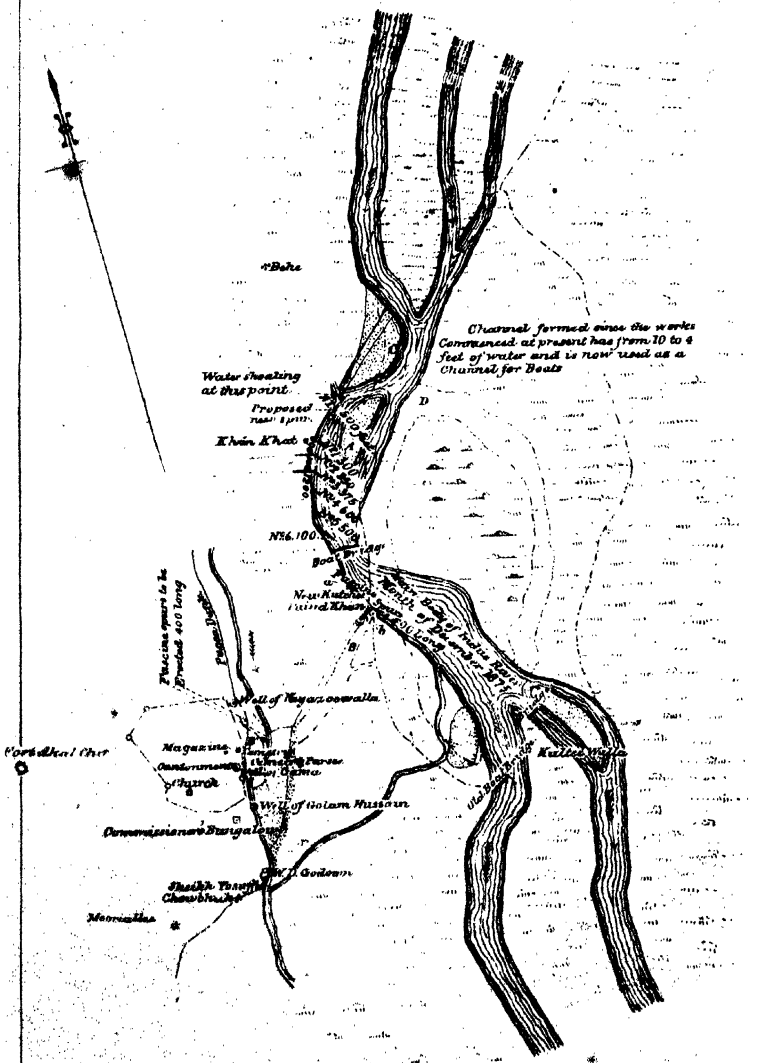
The length of the two floating spurs *a* and *b* will be about 250 feet; those at 3 and 4 will be 600 feet; those at 2 and 3 will be about 350 feet.

In March the river begins slowly to rise, and a small channel, which leads down towards the corner by the Commissioner's house, becomes navigable. Here two spurs would then be commenced; for fascines, which would now be carried by land, could then be carried by boat to near the site of the proposed spurs: and this would effect a great reduction in cost of material, without affecting the scheme for protection of the

PROTECTIVE RIVER WORKS AT DERA ISMAIL KHAN.

JANUARY 1875.

Scale 2 miles = 1 inch.



station, as the water will not rise sufficiently to come down the nullah B, should it ever do so, until the beginning of June.

The actual construction of spur 5 commenced yesterday; some delay was necessarily caused in collecting materials, especially that of stone, which had to be brought from a place some 40 miles up the river.

A large quantity of fascines has been made, also rope, cables and frame-work for stone anchoring; a pile driver has also been rigged up, and piles collected. The works will now proceed rapidly, as material in abundance is at hand; work is being pushed on with the utmost vigour.

C. H.

Extract of letter from MAJOR-GENL. J. D. CAMPBELL, *Supdg. Engineer, 3rd Circle, Punjab, to Secretary to Government, Punjab, Public Works Department.—Dated 25th January*, 1875.

Lieutenant Hoskyns's proposals appear to be judicious; but he is wrong in stating that the main stream last year went down the channel D; the main stream was in the broad course marked by dotted lines. The spur made last year near the village of Kachi Pind appears not only to have caused the silting up of the mouth of channel B, but also the throwing up of the low bank below the mouth, where the dotted lines show that the main stream ran last year. The set of the river at the mouth of old channel B is now evidently towards east bank. The cutting which is reported between the village of Khán Khát and the bridge-of-boats appears to be the greatest evil at present, and I think it would be advisable to try and revet this bank with trees laid along *a*, as well as to form the proposed spurs at 5 and 4; the spur *b* would be more effective, if thrown back against the high bank and formed on the low sand bank in much the same relative position to what it now occupies.

There should be more of the pile and fascine spurs at the main bank opposite cantonments than the two proposed. In undersigned's opinion there should not be less than four, and all against the main bank. The actual cutting which occurred last year below Commissioner's house is not shown, as the dotted lines stop just where the cutting began.

J. D. C.

From MAJOR-GENL. R. MACLAGAN, *Secy. to Government, Punjab, P. W. D., to Supdg. Engineer, 3rd Circle, Punjab.—Dated 15th February*, 1875.

Lieut. Hoskyns's proposals appear right. But the Exec. Engineer,

Major Thorold, who has now joined, will exercise his discretion in making any modifications which the state of the river may show to be necessary.

The objects of the works now in hand, or to be undertaken, are correctly stated by Lieut. Hoskyns in his letter. And the mode of executing the works seems, so far as a judgment can be formed from the map and clear description furnished, to be suitable.

It appears still desirable, as before suggested, with the view of directing the stream, if possible, while it is low, away from the right bank, to make an endeavor to close the channel at *b*, where Lieut. Hoskyns's second spur is proposed; and by a spur at the south end of the island, placed as may seem best according to the form and height of the island at the time, to help the current eastward. But the mode of doing this, and the usefulness of having such a spur at all, it must be left to the Exec. Engineer on the spot to determine. The Supdg. Engineer also will soon be at Dera Ismail Khán.

With reference to the Supdg. Engineer's proposals about the spur *b*, Lieut. Hoskyns has explained that it is a low-water spur only.

The revetting with trees of the bank between the village of Khán Khát and the boat-bridge would be a large business, and costly; and it is doubtful whether it would be so efficacious as the other arrangements proposed.

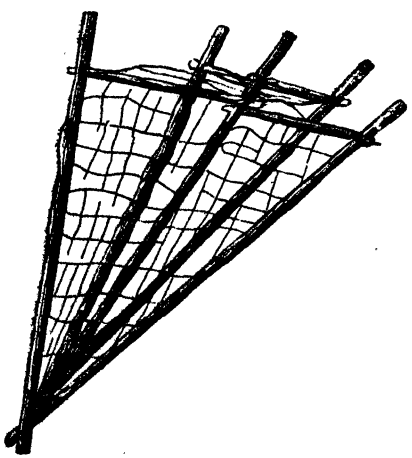
R. M.

Report by MAJOR R. G. THOROLD, R.E., *Exec. Engineer.—Dated 15th March*, 1875.

On arrival at this station at the end of January 1875, the river was cutting away the west bank at the rate of about 20 feet daily. I found that to prevent this two spurs (now marked 4 and 5, *Plate* LI.) above bridge had been commenced, formed of trees, and below bridge two fascine spurs (marked *a* and *b*) were in course of construction to protect the mouth of a channel the river took last year, flowing almost directly on to the station, but which had silted up for about 200 yards inland from the present bed of the river.

Accompanied by Lieut. Hoskyns, R.E., who was then in charge of the Works, I went up the river and carefully examined it, and decided on placing spurs as now shown, viz., Nos. 1, 2, 3, in addition to Nos. 4 and 5 already commenced, which arrangement was approved of by your Office letter No. 616 of 12th February, 1875.

Mode of forming Tree Spurs.—These spurs were commenced in water, varying in depth from twenty feet to fourteen feet, and were constructed as follows:—viz., a warp was made fast to an anchor laid out in the river a little beyond the end of the intended spurs, and some 50 feet or more above the line of spur, the other end being made fast on the bank some distance above the spur. A tree with anchor and cable was placed on the boat, and the boat was then warped out from the bank by means of the warp alluded to, and when opposite the place where the tree was to be placed, the anchor was let go, the shore end of the warp slacked off, and the boat allowed to drop down with the current, until at the place where the tree was to be thrown in;—where it was then thrown overboard, the cable from the anchor having been previously attached to the stem. Where the length of the spur admitted of the arrangement, two boats were employed, one loading, while the other discharged its cargo. The anchors were formed of a frame-work of wood, as shown in the sketch, covered with coarse netting of grass rope, and then filled with stones; each anchor contained about thirteen maunds of stone. The trees were put one on top of another until the spur rose above the level of the water: one portion of the spur being completed before another portion was commenced; and when any gaps occurred, as was constantly the case owing to the lower course of trees settling down in the sand, these gaps were at once filled up. It was attempted to economise the number of anchors by attaching two cables to one and buoying the second, so that one anchor might serve for two trees, but in practise this had to be given up owing to the difficulty of obtaining buoys of sufficiently floating power; and on consideration and careful watching the work, it was deemed better for the general security of the work that each tree should be firmly kept in position by its own anchor.

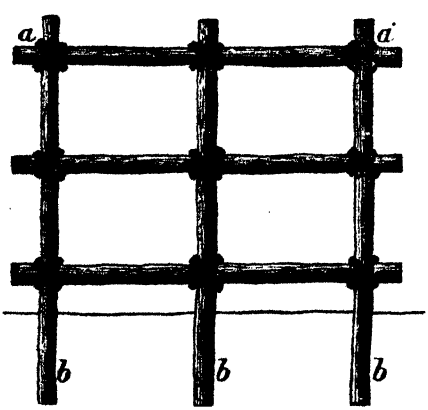


Fascine Spurs below Bridge.—At first a double row of piles were driven

with a distance of six feet between the rows, in the direction of the spur. These piles were driven about ten feet into the sand, and were eight feet apart from centre to centre.

Fascines.—The fascines are made twelve feet long and one foot in diameter properly made on fascine horses, and choked with chokers exactly similar to those in use in field works. Three fascines were bound together, and let down between the piles, and when in their place a second lot of three bound together and placed, thus making up the six feet between the piles; ropes were attached to each lot of three fascines and brought up to the surface of the water, (their use will be mentioned.) As soon as the length of the spur had been layed with one course of fascines, a second was placed, breaking joint with those previously put down, and the ropes from the first or bottom course were passed through the second, and so on, until the work came above water, when the whole were bound together.

It was, however, found that the bund lost its shape and intermediate piles were driven to try and support it. Finding, however, that notwithstanding all the trouble taken, the piles became very loose, so much so that in many cases I could move them easily with one hand, it was resolved to discontinue the use of piles and adopt another course. A boat was fitted up with two derricks, one fore and one aft, and a platform, as shown in sketch, of sound timber constructed between the derricks, the ends *b*, *b*, *b* projecting over the gunwale of the boat and at *a*,*a*, the tackles from the derricks were attached. On this platform six fascines were placed longitudinally, firmly bound together, and the space between filled with stone, making a level surface; on this a second layer of specially made short fascines were placed transversely and treated in a similar manner, and then a layer of longitudinals, the whole being firmly bound together, a cable was then passed round the whole raft and attached to an anchor, the boat warped out to its place,



anchor let go, and then when the boat had dropped down to its proper position, the tackles attached to the derricks and platforms manned, and the latter being lifted up at an angle, the raft slid off by its own weight and settled in its place. This is practically found to be the readiest method of forming these spurs.

It is further proposed, and included in the estimate submitted, to construct two more fascine spurs on what is at present dry land at or about a place marked B', in *Plate* LI., so as to protect the bank near the Commissioner's house, should the main stream again this year find its way down this channel.

Effect of the Spurs.—The work was commenced on the 15th January, 1875, since which time a very large accumulation of silt has formed behind each spur, and the west bank between No. 1 Spur and the fascine spurs has quite ceased to cut away. On one occasion, I noticed that a large quantity of earth had fallen in at the spot where No. 6 Spur is placed, due more, however, to the effect of rain acting on old cracks than from the action of the river; but as the ground is low here, and is the mouth of a small water channel, it was deemed advisable to protect it by means of a short spur, since which time the bank has remained secure. Above No. 1 Spur the cutting has also ceased, but this bank is very sandy, and is exposed to the full force of the current, which flows in the direction shown by the arrows; it is, therefore, as I suggested on the occasion of your visit, better to erect another spur at the point marked A 1, and I would urge the fololwing reasons:—

1*st.*—The main force of the current impinges directly on this bank, as shown by the dotted line, and the bank between No. 1 Spur and A 1 is very weak being loose sand.

2*nd.*—Although the island marked A is rapidly cutting away, part of it being now under water, and the remainder cutting rapidly away (from 10 to 20 feet daily), it would, I think, be a great assistance to this, if the stream was diverted towards this island at a higher point than it is now.

3*rd.*—Though, as stated in the first reason, the main stream follows the course of the arrows and dotted lines, still there appears to be a likelihood of the river changing its course and coming to the west side. The old course of the river D has silted up, and the water is shoaling daily; judging by sounding made, since

the work has commenced, a new channel, with from 4 to 10 feet of water, has been formed through the sand bank C, and is now used by boats; and the upper end of this sand bank is also cutting away as has been shown on the tracing. These changes would seem to indicate a change of direction in the current, and to meet this and counteract any tendency to cut in behind Spur No. 1, as also to protect the bank, suggests that No. A1 should be placed.

My first idea was to attack the river at this point, but I hesitated to do so on account of the expense; at that time there was 30 feet of water, and after giving much consideration to the matter I thought it better to begin lower down the stream. However, I am now of opinion that the work should be done, and am, however, glad to say that nothing has been lost by the delay, but, on the contrary, as owing to the formation of the new channel through the sand bank, much silt is accumulating about this point, and the depth of water is reduced to 18 feet and less in some places.

In accordance with your verbal sanction, I have directed Spur A1 to be commenced.

Judging from the direction of the small channels formed through the island A, there is no doubt but that the effect of the spurs already constructed has been to throw the current towards the opposite bank.

Below bridge the two fascine spurs have accumulated a very large amount of silt behind them, and I think will protect the mouth of the channel they are placed to protect. I have not as yet fully considered the actual position of the spurs to be placed near the Commissioner's house, as the other portion of the work was so very much more important; but am collecting material for the work near the site, and will give this portion of the work equal consideration with the other part.

Estimate framed by MAJOR R. G. THOROLD, R.E., *Exec. Engineer, of the probable Cost of constructing Spurs on Indus River at Dera Ismail Khán.*

This estimate provides for the protection of the Station of Dera Ismail Khán from the River Indus.

The river was cutting away the right (or west) bank at the rate of twenty feet daily, towards the end of January, and to avoid this, seven

spurs, formed of trees lashed to stone anchors, are being thrown out in the positions marked on the plan.

Spur No. 6 was found to be necessary to protect the bank, where it showed signs of weakness from the effect of the back water from No. 5, and also to protect the mouth of a small nullah.

Spur No. A1 was verbally approved of by the Supdg. Engineer, on the occasion of his visit to the works, and has been found to be necessary, as the current impinges directly on the bank about this point, and from there to Spur No. 1 flows close to the bank, which is very weak here, being nearly all fine sand.

The depth of water in which the work is carried on varies from twenty to fourteen feet, and though when a spur was first commenced, the water might be shallower at a little distance from the bank than it was close to it, still it was found practically the depth of water continues much the same along the length of the spur as that at which it was at first owing to the scour.

It has been found necessary to repair the tree spurs from time to time as the lower trees settle down deeper into the sand, and then more have to be added to fill up the breaches. A provision has accordingly been made in the estimate for this, as it is anticipated that when the river rises, these repairs will necessarily be more frequent.

Although the rate shown in the estimate per running foot for tree spurs is more than that for fascine spurs, it is in reality far more economical to employ trees above bridge for the following reasons :—

(*a*). On account of the depth of water a very large number of fascines would be required to bring the spur above water, and then the rate would rapidly increase "above the fascine spur" rate in the estimate, the difference of depth of water between the two places being about 12 feet.

(*b*). The difficulty of obtaining a sufficient supply of brushwood, and the price would rapidly increase with the length of lead from where it is cut to the works.

Below bridge, two fascine spurs are placed to protect the mouth of a channel (B), through which the river ran last year directly on to the station, but which has now silted up, and it is of importance to protect this natural dam at the mouth of this channel as much as possible.

It is further proposed to place two fascine spurs on the bed of this

channel (now dry land) at or near to the point marked B', so as to divert the current should the river enter this channel again; and for the same reason, and also to protect the bank, it is proposed to place a fascine spur near the Commissioner's house, as this portion of the bank was cut away last year.

The exact position of these spurs has not yet been definitely determined upon, but they are shown near to where they are to be. It is intended to postpone the construction of these spurs for the present, until there is more water in the small channel shown near the Commissioner's house, because at the present transport of material to this point would be very expensive, whereas by a little delay water-carriage will be obtainable.

The effect of the spurs, as far as they have been made, has been to prevent the bank cutting away, and to cut away a great portion of the Island A, thus showing that the direction of the stream has been diverted. Silt is also rapidly forming behind the various spurs, and where there was ten feet of water behind No. 5 at the end of January, there is now only as many inches.

Working against such a great and varying force as the River Indus, and with banks of such a fragile material as loose sand, it is impossible to estimate exactly what the cost will be; and I cannot state positively that this estimate will cover the cost of the work; but at the same time judging from repeated observation of the set of the current, I am of opinion that from No. 1 Spur the force of the current is being diverted, and that there is every hope that the stream may be so changed during the present season, that when the river rises the additional volume of water may take the new course that is being made for it; and that the river will entirely change the direction in which it was flowing before the work was begun.

Specification.

The tree spurs to be made at the points marked on the place, and of the lengths prescribed.

Each tree to be firmly secured by a stout cable of grass rope by its butt to an anchor made of a wooden frame covered with grass rope net and filled with stone; each anchor to contain about thirteen maunds of stone.

The anchor to be dropped some distance in front of the spur, the distance varying with the length of cable and depth of water, but always so

far in front of the bund that when the tree is placed in position the cable will be nearly taut. When the anchor is placed the boat in which the tree is, will drop down-stream, until at the place the tree is to occupy; the tree then to be placed in position.

The spurs are to be brought up above water before being lengthened, *i. e.*, the bottom course of trees are not to be put in first, but continued as the spur rises above water, so as to form a protection to the bank as rapidly as possible.

Whenever any breaches occur in the spurs owing to the settlement of trees, or other causes, they are to be made good at once.

The fascine spurs will be constructed of rafts attached to stone anchors, and placed in position from boats; the rafts being placed so as to break joint as much as possible.

The fascines for the fascine spurs are to be constructed of good long brushwood; they are to be made on fascine horses, and properly choked by means of fascine chokers, until they are one foot in diameter, and are to be well and securely bound.

Their length is to be twelve feet, excepting some specially made about six or seven feet of the above diameter, the use of which will be described hereafter.

The rafts are to be constructed as under:—Six longitudinal fascines are placed close together, and firmly bound together. The spaces between them being filled in with stone, thus making an even surface; on this a row of short fascines to be placed transversely, the spaces on the upper side being filled in with stone, and then another course of longitudinal fascines placed on, and the whole securely bound together. A cable is then passed round the raft and secured to a stone anchor.

Abstract of Cost.

ft.		Rs.
2,725	Tree spurs, at Rs. 7-8-0 per foot, ...	20,438
No.		
2,000	Fascine spurs, at Rs. 4-15-0 each, ...	9,875
	For keeping the spurs in repair up to May, by re-placing trees where those put in hand sunk, ...	7,800
		38,113
	Add Contingencies, at 5 per cent., ...	1,956
	Grand Total Rupees, ..	40,069

R. G. T.

No. CLXXVII.

EXPERIMENTS ON CEMENTS AT BANGALORE.

[SECOND

Concluding Report of Experiments on Madras Cements and Limestones.

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Experiments on the relative adhesion of mortars to brick and to stone.—In the former series of experiments adhesive strength was tested only with regard to bricks; but I found that these, although of excellent quality, often yielded under a strain insufficient to rupture the mortar by which a pair was united. At 300 lbs. to 400 lbs. on the crossed bricks (17 to 22 lbs. per square inch) the bricks peel somewhat at the moment of rupture. Above 400 lbs. the bricks, weakened by a month's immersion in water (often for the second or third time), are liable to break off outside the joint; sometimes the strain will tear a large piece out of one brick, the joint standing perfect. This generally occurs between 500 lbs. and 540 lbs. (28 to 30 lbs. per square inch). Being therefore unable to ascertain the maximum strength of mortars requiring a greater strain than the bricks would stand, I had two dozen pairs of bricks cut out of the burnt stone (gneiss) of Bangalore, and of the same breadth as the clay bricks. With these I was able to test the strength of the best cements. I was somewhat surprised to find that the adhesive strength to stone was invariably greater than to brick; the proportion varied with different compositions, but was on the average 1·7 to 1. This rule holds good in the case of the weakest sand mortar as well as in that of the strongest soorkee or Portland cements.

* *N.B.*—For 'First Paper,' *see* No. CXLVI., Professional Papers of Indian Engineering, Vol. IV., Second Series.

On the best way of using mortars of sand and fat lime—In para. 14 of my last Report,* I stated that "the hardening of this mortar being entirely due to dessication, it is not necessary that the bricks should be soaked in water * * * saturation of the bricks is positively detrimental; it is sufficient if they are dipped into water for a few seconds immediately before laying." I have since made some experiments on this point:—

TABLE I.

Adhesive strength of joints made with mortar of—1, *shell lime paste*; 2, *sand. Means of five trials.*

	Breaking weight.	lbs. per sqr. inch.
	lbs.	
A.—Bricks dry, mortar rather stiff, ...	39	2·1
B.— Do. do. thin, ...	57	3·1
C.— Do. do. but the bricks dashed with water from a pot, ...	67	3·7
D.—Bricks soaked 10 seconds, mortar rather stiff, ...	82	4·5
E.— Do. 2 hours, do.	56	3·1
F.— Do. 2 hours, drained 1 hour, do.,..	67	3·7
G.—Stones wetted, do., ...	136	7·2

These experiments show that the opinion I ventured was correct, the best results being given when the bricks were soaked for a few seconds only, the next best when wetted in the fashion usual with careful bricklayers. However, bad is the best with mortars of this kind.

On the necessity of keeping hydraulic mortars wet—The former series of experiments included numerous examples of the great advantage obtained by the immediate immersion of joints made with mortars of fat lime and soorkee. The rule did not hold good in the case of mortars made with moderately hydraulic lime and soorkee, but it was invariable in the case of fat lime even when the joint had the advantage of being made with bricks already saturated with water. The following series illustrates this point, one of considerable importance in practice. The sample of mortar was not a good one, but the relative strength of the series is not affected by this.

* *Vide* page 67 of No. CXLVI, Vol. IV., Professional Papers of Indian Engineering.

TABLE II.

Adhesive strength of brick joints made with—1, *shell lime paste*; 1, *soorkee, after* 28 *days.*

	lbs. per sq. inch.
A.—Bricks dry, mortar rather thin,..	1·4
B.— Do. dipped in water 1 minute do., ...	2·3
C.— Do. saturated, do., ...	6·7
D.—Same as C., but immediately immersed, ...	16·7

Perfect immersion, though beneficial, is not absolutely necessary. If the bricks C had been kept moist for a month they would have given results nearly as good as D.

I also found that brick joints immersed at once gave better results than those kept 24 hours in air before immersion. Stone joints are not so much affected by dryness, the porosity of stone being so small that the joint retains its moisture much longer. It has frequently happened that joints kept in air have shown nearly as great strength as the immersed joints; but for once that this happens I have found five times that the dry joints are much weaker than those which were kept immersed.

On the best proportions for mortars of fat lime and soorkee to be used in masonry and brickwork.—In Article No. CXLVI., it will be seen that the strength given by different proportions of shell-lime paste and of soorkee from Sappers and Miners bricks was as follows:—

TABLE III.

Composition of Cement.	Adhesive strength.	Tensile strength.
	lbs. per square inch.	lbs. per square inch.
1 Lime paste, 1½ soorkee, ...	20·5	62
Do. 2	11·1	91
Do. 3	17 to 27	95
Do. 4	10	114
Do. 5	9	90
Do. 7	5	57
Do. 10	4·4	50

The results obtained with three parts of soorkee were exceptionally good, while those given by one part and by two parts were exceptionally low,

hence a discrepancy. I therefore made a fresh series of experiments, and found that while the adhesive strength remained very fair with as much as five parts of soorkee, yet that it diminished with each increase. The tensile strength, on the contrary, increased with the proportion of soorkee up to five parts. As this question of the best proportion of soorkee is mixed with that of the substitution or the addition of sand in these soorkee cements, I give the experiments on both in one Table (IV).

The brick joints were immersed at once and tried after 28 days; the brickets were immersed after one day and also tried at 28 days of age.

TABLE IV.

Composition of Cement.	Neat Soorkee Cement.		Cement with equal volume of Sand.	
	Adhesive strength.	Tensile strength.	Adhesive strength.	Tensile strength.
	lbs. per sq. inch.	lbs. per sq. inch.	lbs. per sq. inch.	lbs. per sq. inch.
1 Lime paste, 1 soorkee, ...	32	130	20·8	144
1 do. 1½ do., ...	16·9	145	8·9	120
1 do. 2 do., ...	18·8	130	7·1	116
1 do. 3 do., ...	11·2	125	1*	156
Mean, ...	..	132	..	134

From this table it will be seen, 1*st*, that adhesive strength, though good with all proportions within rather wide limits, yet decreases with an addition of soorkee beyond one part; 2*nd*, that the adhesive strength of these mixtures diminishes still more rapidly when they are diluted with sand; 3*rd*, that for tensile strength the proportion of soorkee is immaterial; 4*th*, that the tensile strength is on the average fully as good when the cement is diluted with sand as when it is used neat.

Another set of experiments showed that a half-part of soorkee is too small a proportion, and confirmed the inference to be drawn from Table

* This is rather low. It may rise to as much as 11·2 lbs. (*see* page 387), but at this point the strength is very capricious.

IV., that the adhesive strength is affected by the addition of sand in proportion of the quantity of soorkee. These experiments were made with a kunkur lime very slightly hydraulic; the joints were tried after 28 days immersion.

TABLE V.

	Neat lime or sand mortar.	Soorkee Cement.		
		Neat.		With equal volume of sand.
	lbs. per sq. inch. Brick.	lbs. per sq. inch. Brick.	lbs. per sq. inch. Stone.	lbs. per sq. inch. Brick.
Lime paste, neat, ...	3·8	..	..	..
Do. 1 sand, ...	2·7	..	..	..
Do. 2 do., ...	7·8	..	..	..
Do. ½ soorkee, ...	..	18·3	27·6	19·4
Do. 1 do., ...	..	29·3	59·3	15·6

From these last two tables, the following practical rules may be deduced:—

(*a*).—The best soorkee cement for masonry is made with one of soorkee to one of lime paste (or an equivalent quantity of slaked lime; after 28 days under water it is stronger than the best bricks, and with stone it stands a disruptive force of nearly 60 lbs. per square inch.

(*b*).—When rapidity of setting is an object, the proportion of soorkee can be increased to two parts; this proportion causes quicker setting, but with some loss of strength.

(*c*).—When economy is an object, the cement made with one of soorkee to one of lime paste may be diluted with an equal volume (1½ parts) of sand; the mortar will be as strong as good bricks.

(*d*).—When greater economy is an object, especially in the case of rubble masonry, where a great quantity of mortar is used and the work is more of the nature of concrete (requiring tensile rather than adhesive strength), two parts of soorkee may be used to one of lime paste, and the cement diluted with an equal volume (2½ parts) of sand.

(*e*).—Where the rubble masonry is required to be specially good, two proportions may be used:—one lime to one soorkee for laying the stone; one lime, two soorkee, two and a half sand for grouting; the latter of course to be filled in before the jelly is placed in the interstices of the stones.

(*f*).—The latter proportion, one lime two soorkee, diluted with an equal volume (two and a half) of sand, may advantageously be employed where the bricks are of inferior quality. It is still much stronger than ordinary country bricks. I prefer throwing in the sand after the lime and soorkee have been mixed together in the mill with a full quantity of water.

(*g*).—When the lime is more or less hydraulic, the foregoing proportions still hold good. There is some advantage in the lime being hydraulic, as the adhesive strength of the soorkee cement which it yields is less dependent on moisture than is the case when fat lime is used. For superstructures, a soorkee cement made with fairly hydraulic lime gives perhaps the best guarantee of strength.

On the use of Soorkee cement for concrete and for plastering.—It has been seen that the greatest tensile strength was obtained by the use of three or four parts of soorkee to one of lime paste, and that this cement would bear dilution with an equal (three parts), or even more, of sand not only without loss of tensile strength, but even with positive gain, besides acquiring hardness. I would not, however, advise greater proportions than three of soorkee to be used, as beyond this limit the cement becomes soft; nor more than an equal volume (or perhaps a volume and a half) of sand in dilution. The proportions I have mentioned, one lime, three soorkee, three sand, may be taken as the standard when the lime is fairly rich. When the lime is meagre or slightly hydraulic, the proportions of soorkee may be reduced to two with advantage. The standard proportion gives a tensile strength (after 28 days, of which 27 in water) of 127 lbs. per square inch, according to the experiments in Article No. CXLVI., or even more in the present series. The mean tensile strength of the four compositions given in Table IV. is 134 lbs., the most economical of them being the best. This strength is little inferior to that of Portland cement diluted with an equal volume of sand, and far superior to that of the more diluted mixtures ordinarily used.

For work in large masses, such as foundations or large blocks of artificial stone, I can see no objection to the use of this concrete mortar in any place where the material can be procured. But for thin work, such as plastering, there is an objection, though not so formidable a one as would at first appear. There is no doubt that soorkee mortar plastering has a great tendency to crack; this can be in a great measure, if not entirely, obviated by keeping the surface constantly wet, and by good workmanship; yet these precautions are often inapplicable. However, I have not found much practical disadvantage in this respect; I admit that cracks are unsightly and impair the water-tightness of walls, but they can generally be avoided in hydraulic works where impermeability is most important, or in the interior of buildings; and in work exposed to the sun, such as the outer plastering of a building, they are of little consequence, and are filled up when the walls are whitewashed or colored.

I have used this mortar in making terrace roofs; they are lighter than those made with common mortar, as only two or three layers of tiles are required; they do not get saturated in wet weather, and much less timber is needed to support them, not only from their lightness but also from their strength. In many cases the timber is principally useful as a centering, and could be in great part removed after three or four weeks. If I may be excused giving my experience on a part of the subject which is hardly within my professional competence, I would submit the following examples of work done with this mortar:—

(*a*).—I made a verandah to a stable, it is 36 feet long, 7 feet wide; supported on the outside by four stone posts and bearing on three bressummers of jungle wood, each 10½ feet between the supports, and of very light scantling (4 inches deep, 3 inches broad). The rafters are bamboo, the reapers junglewood. The roof is 2 inches thick, composed of two layers of flat tiles, the upper layer laid in and covered with the soorkee cement mortar.

(*b*).—I also made an experimental arch, 10 feet in span with 10 inches rise; it is flat above, being 12 inches thick at the haunches and 2 inches at the crown. Its width is 2 feet; it abuts on two piers each of 2 feet square. The middle half of the arch, where it is less than 4 inches thick, is made of mortar alone (one lime, two soorkee, three sand), the remainder of concrete,

two volumes of gravel with one of mortar. Owing to the thinness of the arch, and either to my neglect of protecting it from the sun by a covering of wet sand, or perhaps to some settlement in the piers, two cracks appeared, one across the crown, another at a foot and a half on one side of the first. These cracks were cleaned out to the depth of one-third inch and filled with Portland cement and sand; and a few days afterwards (one month after the arch was made) the centerings were removed. It was then seen that the cracks extended right through the arch; yet there are no signs of weakness and it supports a weight of 1,000 lbs. on the crown.

(*c*).—The impermeability to wet of plastering made with this mortar is so good, that brick in mud walls are perfectly protected by it, even when exposed to constant wet.

Small cisterns in earth, made of brick in mud, half a brick thick, and plastered inside with this mortar, can be filled with water within a few hours of the plaster being polished.

(*d*).—For floors and walls of bath-rooms this mortar is well adapted; it does not become saturated with water; it is always clean, and as a floor it lasts much longer than the ordinary mortar.

On the best way of using mortars of sand and hydraulic lime.—In the foregoing observations I have referred principally to soorkee cements made with fat lime, such as that obtained from shells, from Cuddapah stone, from chalky kunkur, &c., (*see* page 396.)

Where hydraulic limes are procurable, there is of course less advantage in the employment of soorkee cement mortar, except from economy, and the use of sand mortar then has advantage in certain circumstances. Sand mortars of hydraulic lime doubtless deteriorate by keeping, and by having to be beaten up again when required for use, though to a less extent than soorkee cement mortars.* Sand mortars also require less moisture during setting; they do not demand such skilled labor or so much supervision. Moreover, good hydraulic lime is often procurable very cheap in parts of the country where good soorkee may not be obtainable except at a considerable cost. For these reasons sand mortar is sometimes preferable to

* Where the work does not require any very great strength, as in the case of plastering, or of grouting for rubble masonry, soorkee cement mortar may be kept for as much as a week without notable detriment In this case, the mass should be broken up and allowed to dry rather than to set, so that the powder can be beaten up again with water when required.

soorkee cement mortar, especially for petty works. To give an example, in Bangalore excellent hydraulic lime can be procured, but at a high price, 1 rupee to 1½ rupee per parah; as soorkee can be made very cheaply it will still be economical to use soorkee cement mortar. But 20 miles away the same lime may cost only half a rupee, while it is difficult to ensure good soorkee being used: water may have to be brought from a long distance, and supervision may necessarily be irregular. In this case there is manifest advantage in using sand mortar, of course on the understanding that the lime is up to a certain hydraulic standard. This standard I place at the ability to set within seven days under water when tested by Vicat's needle, (B. in Table VI).

But whatever combinations be used in making mortar with hydraulic lime, I would recommend that the usual method of slaking and beating the lime be abandoned. The hydraulic limes from kunkur stone are usually so little homogeneous that the nodules may separate, when slaked, into flakes of fat lime and cores so strongly hydraulic as to be incapable of slaking. The latter are separated by beating and usually rejected as 'kuppy'. I need hardly say that I am supposing the lime to be well burnt; and since paying attention to the subject, I have found, as far as my small experience goes, that the Indian lime-burner works very honestly. Any quantity under 10 per cent. of carbonate remaining in a lime may be taken as moderate, and I have never found this number exceeded in a Bangalore quick lime; 4 or 5 per cent. is the more usual number. These facts, which I obtained since using the calcimeter regularly on every sample of lime burnt or bought, are in correction of my remarks on the nature of kuppy in Article No. CXLVI., page 68. The cores, when hydrated and left to the action of the air, soon become carbonated and simulate a refuse of badly burnt and very meagre limestone.

The following experiments illustrate the ill-effects of the usual treatment of hydraulic lime. The specimen was the common lime of Bangalore, bought from the bazaar; it is made from a good clayey kunkur, and had in this case the following composition:—

Silicates, ...	40
Carbonate of lime, ...	8·8
Quick lime, ...	(51·2)

When the lime was slaked and beaten, the kuppy was found to contain 10 per cent. of carbonate.

TABLE VI.

	Setting days; with the 3 loaded needles.			Adhesive strength, neat; bricks 28 days immersed.
	A.	B.	C.	
Lime slaked and beaten free of kuppy,	8	13	24	2 lbs. per square inch.
Kuppy alone, ground, ...	¼	2	2½	25·4*
Lime slaked ground with kuppy, ..	8	15	28	2
Lime ground quick and then slaked,	3	4	7	19·6
The same, with equal volume of kuppy added, ...	1	2	3	27·6*

From these experiments it would appear that the proper way to obtain the full hydraulic properties of the lime is to grind it quick and slake it afterwards. Slaking it and then grinding it yields very poor results; I surmise that the kuppy when hydrated already is incapable of exercising any influence over the remainder of the lime, but if distributed through the lime before slaking its full effect is obtained.

From some experiments on a large scale, I may state that there appears to be no practical objection to this plan of grinding hydraulic lime before slaking. The quick-lime is ground in the common lime mill and sifted through a 12-mesh sieve; it may now be left heaped under cover; it slakes spontaneously without any loss of hydraulic properties and absorbs carbonic acid very slowly. When the sand to be used is dry I would recommend that the lime thus ground be at once mixed with it (two or even three parts) and left until required for mixing. One advantage of this plan is that the lime is less liable to be stolen.

Absorption of carbonic acid from the air affects a heap of ground quick-lime very slowly; some Bangalore quick-lime ground very fine and left undisturbed in a bucket was found after four months to contain the following proportions of carbonated lime:—

At the surface, ...	9·2 per cent.
One inch below, ...	5·2 „
In the middle, ...	4·8 „

Some of the same lime kept in a bottle contained 4·6 per cent. of carbonate. The lime left in the bucket had increased in volume by about one-half; when reduced to paste it gave out but slight heat, being nearly completely slaked; its hydraulic qualities were present as when it was fresh.

* The bricks broke off at this strain, joints standing good.

On mixing the materials for soorkee cement mortar.—If the lime is fat and slakes freely, leaving little or no 'kuppy' except foreign matters, it can be slaked and mixed with the soorkee, the mixture being kept until wanted. The volume of lime after slaking is rather variable, and as the paste is taken as the active volume of the lime, it is needful to ascertain how much of it is equal to one part of paste. The following examples show the quantity of slaked lime and paste obtained from some typical limes. All, except the first, were measured ground; 110 parts quick lime ground are roughly equal to 100 or 120 of it in lump.

TABLE VII.

Sp Gr. in bulk.	Kind of Lime.	Quick.	Slaked.	Paste.
1·06	Shell lime (fat) not ground and underburnt,	100	200	133
1·05	No. 13 (slightly hydraulic), ...	100	252	132
·91	„ 16 (slightly hydraulic), ...	100	210	144
·91	„ 26 (fair hydraulic), ...	100	200	108
1·04	Bangalore (fair hydraulic), ...	100	149	100
1·	No. 75 (good hydraulic), ...	100	112	88
·96	„ 24 (very strongly hydraulic), ...	100	111	63

Roughly speaking the fatter a lime the more slaked lime and paste does it produce. Quick lime ground gives more slaked lime than when slaked in lump; but the quantity of paste will be the same.

Fat lime slaked in lump, 1 paste = $1\frac{1}{2}$ slaked or $\frac{3}{4}$ quick.

„ „ ground, 1 „ = 2 „ $\frac{8}{3}$ „

Hydraulic „ „ 1 „ = $1\frac{1}{3}$ „ 1 „

If a hydraulic lime is to be made into soorkee cement, it may advantageously, though not necessarily, be treated in the same way as for sand mortar. The ground lime is mixed with the proper proportion of soorkee and left heaped under cover until required. If a fairly hydraulic lime, one part of ground lime (which is about equal to its volume in paste), is mixed with two parts of soorkee for concrete, rubble masonry or common brickwork, with one part if for the best masonry or brickwork. When required, three parahs of the mixture are placed in the mill and mixed

along with a sufficiency of water. If mortar be required, then to the mixed cement two to three parahs of sand are added, according to the quality of the work.

When the lime is fat and slakes perfectly, there is no object in grinding it before slaking; one and a half part of slaked lime (equal to one of paste) can be mixed with two or even three of soorkee if for concrete, with one of soorkee if for fine brickwork or masonry. When required for use three parahs of this mixture are taken, mixed in the mill and sand added if required.

I prefer to add the sand after the cement has been mixed. If the mortar is for concrete, it is important that it should be as stiff as possible, and this stiffness is attained by mixing the cement with sufficient mortar to temper it well and adding the sand afterwards. When the whole of the materials are placed in the mill at once, much more water is required, and the mortar is generally too thin for concrete. There is no difference in the strength (tensile) of the concrete whichever way it is made (*see* next section). When the ground quick lime and soorkee have been kept together as I have suggested, it is advisable to mix them well into paste before adding the sand in order to ensure perfect slaking. I have never found any defects from this possible cause, but it is a reasonable precaution to take. After the sand is added very little more mixing is required.

But I have reason to believe that, while tensile strength is not affected by the addition of sand being made before or after the mixing of the cement, or by rough mixing, the adhesive strength is often seriously affected. In carefully conducted experiments on a small scale, the effect of sand is often capriciously detrimental to adhesive strength, and on a large scale the risk of reducing it should be avoided as much as possible. In the experiments detailed in page 388 with a sand mortar made from soorkee cement, containing three parts of soorkee to one of fat lime, the tensile strength was as nearly as possible the same under both conditions of mixture, but there was a considerable difference in the adhesive strength of the mortar. When the sand was added *after* the mixture of the cement into paste the brick joints broke at 170, at 198 lbs., giving a mean of 203 lbs., or 11·2 lbs. per square inch. When the sand was added to the dry ingredients the adhesive strength was 120 lbs., 156 lbs., 0. Even eliminating the last, as possibly an accident, the mean is 138 lbs.

or 7·7 lbs. per square inch. I must say that both were good, much better than the standard results given in Table IV. But the effect of sand or adhesive strength appears to be very capricious.

The following case in practice illustrates this point. The mortar used in building the additions to the Division Cutcherry at Bangalore was made thus:—Baskets of slaked kunkur lime, of broken brick and of sand, in equal numbers, were thrown into a steam mortar mill, along with a sufficiency of water; and, as the mixing was done with great rapidity, in less than five minutes the batch of mortar was taken out, apparently well mixed. The composition of this mixture may be taken as 1 lime-paste, 1½ soorkee, with 1½, or somewhat less than a volume of sand. The tensile strength of this should be about 116 lbs. per square inch, the adhesive strength at least 9 lbs. per square inch (Table IV). The actual results obtained were as follows:—

Tensile strength, 28 days in air, 247 lbs., or 110 lbs. per square inch.
Do. do. in water, 252 lbs., or 112 lbs. do.
Do. 118 days in water, 353 lbs., or 148 lbs. do.
Adhesive strength, 28 days in water, 110 lbs., or 5·5 lbs. do.

Now the tensile strength is very fair, 112 lbs., being a close approximation to the strength given in the standard experiments, showing how little the mode of mixture affects tensile strength, but the adhesive strength 5·5 instead of 9 or more is decidedly poor. In fine, I consider that it is better to add the sand after the lime and soorkee cement has been thoroughly incorporated, with the requisite quantity of water.

On the proportion of actual strength to the tensile strength obtained with standard brickets of mortar.—When using my lever-testing machine, I take care that the weight is drawn along the lever at a regular speed, so that the increase of strain is equal; it is generally at the rate of 5 lbs. per second, perhaps somewhat quicker in very strong specimens. The following experiments were made with brickets of soorkee cement mortar to ascertain what proportion the actual strength of the mortar bore to the breaking weight The composition of the brickets was:—

Shell lime slaked 1½ = paste 1
S. M. brick soorkee 3
} 1 cement.
Sand (vol. = vol. of mixed cement) 2½ 1 sand.

They were 28 days old, of which 27 under water.

First series.—Sand added after mixing the cement.

Bricket A. breaking weight, 314 lbs.
B. ,, 293 lbs. } Mean 311 lbs., or 138 lbs. per square inch.
C. ,, 326 lbs.

The mean breaking weight being divided into tenths, three other brickets were tested by a portion of the strain at first, the remaining tenths being added at intervals of time. The following were the times during which the increasing strains were supported:—

Bricket D. stood for 10 minutes, ·5 of the mean breaking weight.
,, 15 ,, more ·6 ,, ,,
,, 10 ,, ,, ·7 ,, ,,
,, 15 ,, ,, ·8 ,, ,,
,, 3 ,, ,, ·9 ,, ,,

Total 53 minutes when it broke.

Bricket E. stood for 3 minutes ·75 of the mean breaking weight.
,, F. 20 ,, ·7 ,, ,,
,, 20 ,, more ·75 ,, ,,
,, 22 ,, ,, ·8 ,, ,,
,, 13 ,, ,, ·85 ,, ,,

Total 1 hour 15 minutes when it broke.

Second series.—Sand added to dry lime and soorkee.

Bricket G. breaking weight, 284 lbs.
H. ,, 317 lbs. } Mean 306 lbs., or 136 lbs. per square inch.
I. ,, 317 lbs.

Bricket J. stood for 5 minutes ·6 of the mean breaking weight.
,, 18 hours ·75 ,, ,,

Total 18 hours 5 minutes when it broke.

Bricket K. stood for 1½ hours ·6 of the mean breaking weight.
,, 1½ ,, more ·75 ,, ,,

Total 3 hours when it broke.

It would appear then that the breaking weight being 100 when attained rapidly, 60 could be supported for at least twenty-four hours perhaps longer, and 75 for a time varying between three minutes and eighteen hours. The tenacity appears to be favored by a slow increase of the strain. It is probable that the permanent strength of this mortar would be little short of 50 per cent. of its breaking weight.

Experiments with Limed Soorkee Mortar.—I have not had time to pursue my experiments on cement made with the improved, or limed,

soorkee, but such further experience as I have had shows the value of this puzzolana where quick setting and hardness are required.

A.—Soorkee made from blue clay treated with 20 per cent. of lime. A cement made of one shell-lime paste two soorkee set hard (c needle) in sixteen hours. It gave the following results:—

Adhesive strength after 1 day's immersion, 2·2 lbs. per square inch.

" 28 day's " 25 lbs. " (bricks broke).

" stones 28 " " 48 lbs. "

Mixed with equal volume of sand.

Tensile strength after 28 day's immersion, 156 lbs. per square inch.

" " 118 " " 201 lbs. "

B.—Soorkee made from common brick clay treated with 10 per cent. of lime.

A cement made with one shell lime one soorkee gave an extraordinary rapidity of adhesion.

Adhesive strength after 1 day's immersion 5·8 lbs. per square inch.

" " 28 day's " bricks broke at 25 lbs.

Mixed with equal volume of sand.

Adhesive strength of bricks after 28 day's immersion, 28·7 (bricks broke).

" " stones " " 49·5 lbs. per square inch.

From pressure of time I had to discontinue the experiments.

Experiments with Lime and Clay (twice-kilned cement).—Further experiments with this cement show that it has no advantage over the soorkee cements except in quick setting under water. It sets fully (c needle) within 24 hours, and in the same time attains an adhesive strength of 4·5 to 4·8 lbs. per square inch. Its ultimate adhesive strength is not better than that of the soorkee cements; moreover, it has the disadvantage of being unable to bear dilution with sand. It also has a very poor tensile strength whether neat or mixed with sand. Its quick setting under water is counterbalanced by a loss of strength when immersed at once.

I tried the admixture of magnesite before burning, but the results were not encouraging.

On a process for revivifying Portland cement and rendering it quick setting.—Having a large number of broken brickets of Portland cement (neat) lying about, I burnt some on top of a charge of limestone in my furnace, for different lengths of time, between six hours and twenty

hours. The burnt cement, ground and sifted, was found to be possessed of extraordinary hydraulic energy; while the original cement when new, set in the following times:—A. six hours, B. (Vicat's needle) ten hours, C. 16 hours; this reburnt cement set hard in less than 10 minutes. Two months after burning, the weather being also very damp, about 20 minutes were required for setting. I made some brickets from the reburnt cement when new, not without difficulty, for it set hard before I could tamp it and get it out of the moulds; and I found that the strength, compared with that of Portland cement, was as follows:—

	Seven days old (6 under water),		28 days old (27 under water).
London standard,	178 lbs. per square inch.		
Original cement,	181 lbs.	,,	219 lbs. per square inch.
Reburnt cement,	91 lbs.	,,	153 lbs. ,,

It appears that this cement follows the usual rule of quick setting being obtained at the expense of strength; however the strength, though poor at a week old, is very satisfactory after a month. There are many cases where a considerable sacrifice of strength may be made in order to obtain quick setting, for example in tidal works or in stopping springs.

It is probable that by using the caked portion always found on opening casks of Portland cement (which has been estimated as a wastage of 10 per cent.) or cement which has become unserviceable through age, this quick setting cement could be produced very cheaply. The damaged cement could be mixed with water made into bricks and burnt in a kiln in the usual way.

I found that specimens burnt for different lengths of time were equally good, provided they were not clinkered. The burnt cement grinds easily, no more powerful means than that for grinding soorkee being required. It should be sifted through a 48-mesh sieve and kept in air-tight packages. But it would be well to keep the bricks and burn them only a short time before the cement is required for use.

Results obtained in the examination of limestones from the different districts of the Madras Presidency.—With a view to conciseness, the list appended to this report has been drawn up according to a scheme of description giving—

1*st.*—The physical character of the stone;

2*nd.*—The chemical character;

3*rd.*—The probable or actual character of the lime yielded.

Of these three heads of description, the last is the most important when the character of the stone can be determined by actual experiment on the lime obtained from it. Such a procedure would, however, demand a heavy outlay of time, when several hundreds of stones have to be examined, each stone requiring on the average two or three days' work. But experience shows that attention to the physical appearance of the stone with a short chemical examination will give such preliminary information as will render experiment on the burnt stone unnecessary, except in the case of specimens promising good results. These are unfortunately but few in number, and the information obtained under the first two heads, or even under the first alone, eliminates at least nine out of ten specimens under examination as not being sufficiently promising to repay the labor of burning and practical trial.

Determination of physical character.—The use of the following terms enable the physical description to be given concisely:—

Morphism.	Consistence.	Form of deposit.	Hardness.	Color.
Crystalline ..	Compact ..	Rock	Intensely hard	White.
Splintering ..	Honeycombed	Boulders	Very hard ..	Buff.
Semi-crystalline..	Mammillated	Masses (irregular)	Hard ..	Grey.
Almond-like ..	Conglomerate	Marly lumps ..	Friable ..	Pink.
Amorphous ..	Geodic ..	Nodules*.. ..	Soft ..	Red.
Chalky (or marly).	Sub-geodic ..	Incrustations* ..	Rotten ..	Greenish.
Clayey	Tufaceous ..	..	..	Ochreous.
Sandy	..	..	..	Mottled with mica.

Examination of the numerous specimens sent from all parts of the Presidency show that they may conveniently be referred to the following types:—

I. Chalky or Marly Kunkur.—Sometimes found as soft marl, more often as rounded lumps of chalky appearance, or less soft, of amorphous texture. Sometimes this passes to marble having an effloresced and somewhat crystalline appearance; the marly kind passes to the semi-crystalline type. The lime yielded is generally fat.

II. Clayey Kunkur.—Nodules or incrustations, mulberry-like or mammillated, with very distinct central cavity (geodic), hard but brittle, grey to dark slate color, fracture conchoidal, amorphous and dull, the cavity generally lined with a fine granular layer. Yields more or less hydraulic lime according to the degree in which these characters are present.

* Nodules or incrustations when not larger than road metal or large gravel are known as *kunkur*.

III. Tufaceous Stone.—Irregular masses, of loose and pumiceous texture, perfectly amorphous, light and friable, white or buff color. When the silicates amount to upwards of 30 per cent. as is frequently the case in this type of stone, the lime yielded is of strongly hydraulic character, only differing from a true cement by its comparative slowness in setting.

IV. Semi-tufaceous Stone.—Similar to the preceding; but the character, especially the lightness, less marked. Tends to the semi-crystalline type. Quality depends on the amount of silicates present, but if these be the same as in the preceding type, the lime yielded is equally good.

V. Amorphous Compact Stone.—Generally large boulders or masses of dull granitoid fracture. Rarely homogenous, and yielding usually a lime which is fat or but slightly hydraulic. Sometimes it is of rotten structure, not to be confounded with the friability of tufaceous stone.

VI. Semi-crystalline kunkur boulders or masses of stone.—Generally honeycombed, mammillated or conglomerate, occasionally geodic, of more or less semi-crystalline structure. Color various, often dark grey or red. Contains much quartz, felspar, decomposed gneiss and black mica. Garnets, chlorite, asbestos or lepidolite (golden mica) often present.

The lime yielded is generally fat or only slightly hydraulic. As a rule no quantity of silicates less than 20 per cent. gives it the slightest hydraulic properties.

VII. Almond-like Magnesian Stone "Paloday".—In boulders or compact masses. Intensely hard, fracture dull and almond-like, color yellowish white, frequently with patches of white magnesite visible. Always more or less magnesian. Yields fat lime devoid of hydraulic properties. Called in Tamil *paloday* from its milky or creamy color.

VIII. Semi-crystalline Splintering Rock.—In large compact masses or slabs (Cuddapah stone). Intensely hard, splintering with a clean fracture, grey to bluish black. Usually yields a fat lime, and, if much silicates (30 per cent.) be present, a meagre rather than a hydraulic lime.

IX. Napa Stone.—This is the name (Telugu ?) given to a variety of the preceding; it has a rather smooth feel and fibrous texture. Yields fat lime.

X. Marble.—The marble of Southern India is a kind of calcspar,

resembling alabaster rather than statuary (saccharoid) marble. It is pure and yields a perfectly fat lime.

XI. Shells or Coral.—Yields a perfectly fat lime.

I consider that all these, with the exception of the last, are forms of carbonate of lime dissolved by, and deposited from rain water. The carbonate of lime (and of magnesia) dissolved by rain water out of weathered gneiss and other metamorphic rocks is deposited in the lower parts of valleys. The marley deposits harden and assume in time a crystalline form, varying according to the following circumstances:—

(*a*).—If pure they may crystallize into *marble.*

(*b*).—If magnesian they assume the almond appearance of *paloday.*

(*c*).—If mixed with mica and other debris of gneiss they become *semi-crystalline kunkur.*

(*d*).—If mixed with clay they shrink in drying and form the rounded septarious nodules of *clayey kunkur.*

Chemical Examination.—The analysis of a limestone is an operation requiring a well appointed laboratory and skill in chemical manipulation. Even when a complete analysis is not required, when we only want to know the amount of silicates and of magnesia present, the operation by ordinary good methods is difficult and tedious.* Or even the simplest kind of information, the determination of the amount of silicates (and sand) remaining after solution of the limestone in muriatic acid, is too long for performance in an extended series of investigations. I have devised a method by which a complete analysis can be done in little more than the time usually required for the determination of silicates; and when the percentage of silicates is alone required, I do it indirectly by means of the calcimeter; the process takes but a few minutes and is of considerable accuracy. The original form of the instrument was devised by a German Chemist, Mr. Schiebler, for the determination of carbonate of lime in the spent bone black of sugar refineries; it was a rather complicated piece of apparatus, but I have simplified it considerably, indeed so much that I constructed two instruments with the aid of a carpenter and such materials as are ordinarily found in laboratories.

* In every treatise on limestones with which I am acquainted, the analytical processes laid down are very inaccurate, without any compensation in simplicity or in rapidity of execution. The Authors are not responsible for this; the chapter on analysis being generally quoted, or contributed by another person who has not had an opportunity of testing the processes as to their applicability to the special character of the investigations.

I purpose taking an early opportunity of giving a full description of the calcimeter and its use in the examination of limestones and limes, in accordance with the intimation conveyed in G. O., 5th August 1874, No. 2156; it will be sufficient at present to state the principle of its action. If the carbonic acid gas be expelled from a carbonate by the action of muriatic acid, and the quantity of gas be measured, the equivalent amount of carbonate of lime can be ascertained. Now, if we operate, first on a weighed quantity of pure carbonate of lime, then on an equal quantity of limestone or other impure carbonate, any deficiency in the quantity of gas evolved from the latter (as compared with the quantity evolved in the standard experiment) must evidently be owing to the presence of impurities and be proportionate to their quantity. The character of the silicates can be approximately judged by the appearance of the insoluble residue. They may be sand, mica, clay, silica, &c. The percentage amounts of silicates given in the descriptive list were usually obtained by the calcimeter. They were frequently checked by other processes and found to be accurate.

Determination of the character of the lime yielded by a specimen of limestone.—Great mistakes would be made if the limestones of Southern India were judged solely by their chemical composition. Most of them are anything but homogeneous, and specimens containing as much as 20 or 30 per cent. of silicates may yield a lime slaking with all the energy of fat lime and totally devoid of hydraulic properties. The reason of this is that few of them contain clay, the silicates being the more or less fine *debris* of metamorphic rocks. Yet, on the other hand, it is found that specimens equally devoid of clay but containing a quantity of silicates (of very sandy appearance) which would theoretically render them quite meagre, furnish excellent hydraulic lime, even cement, *e. g.*, the tufaceous stones.

As a rule the quantity of silicates required to impart hydraulic properties is far greater than in the case of the European and American cements of which analyses are recorded. It may also be taken as a rule that the limes yielded by Indian limestones do not show the meagre quality which one would expect from the quantity of inert silicates present. The great variation in composition also produces much practical inconvenience; for a lime which is, on the average, of good hydraulic quality may be

separated, on slaking, into fat lime and a residue of strongly hydraulic lime incapable of slaking.

It was only after considerable practice in experiments on the lime yielded by different qualities of stone that I could venture to depend on the appearance of the limestone as indicative of its quality, though aided by a knowledge of its chemical composition. Even with considerable experience errors may occur; they are, however, on the safe side, for it is hardly possible to pass over a limestone possessing hydraulic properties, the error being always in taking for hydraulic a limestone which is simply meagre or non homogeneous. The physical appearance of limestones, combined with a determination of the percentage of silicates, will then be sufficient to eliminate those specimens which are not promising, and to point out those which are deserving of final experiment after burning. The following table shows the type and chemical character of limestones yielding limes of the different degrees of hydraulic energy :—

Classification of limestones according to the quality of the lime yielded on burning.

Quantity of the Lime.	Type of Stone.	Chemical Character.
Perfectly fat, ..	Shell or coral, ...	
	Marble, ...	
Fat or slightly hydraulic,	Almond-like stone (paloday), ..	May contain as much as 20 per cent. of silicates and yet behave as fat limes every respect.
	Chalky kunkur, ...	
	Amorphous compact stone, ..	
	Splintering rock, ...	
	Napa stone, ...	
Meagre, ...	Semi-crystalline stone, ...	May contain 20 to 40 per cent. of silicates. A stone containing 36 per cent. of silicates would yield a lime containing one-half of silicates which if inert would render it meagre.
	Splintering rock, ...	
Slightly to fairly hydraulic,	Semi-crystalline stone or kunkur,	Containing 10 to 30 per cent. of silicates, the degree of hydraulic energy varying according to homogeneity nature of the silicates, &c.
	Amorphous compact stone, ..	
	Splintering rock, ...	
	Clayey kunkur, ...	
Good hydraulic, ..	Sandy kunkur, ...	Containing 30 to 50 per cent. of silicates.
	Clayey kunkur, ...	Containing 20 to 30 per cent.
	Tufaceous stone, ...	
Strongly hydraulic to cement,	Clayey kunkur, ...	Containing upwards of 30 per cent. of silicates.
	Tufaceous stone, ...	

It may be said that with the exception of some rather rare sandy kunkurs, the only limestones giving really good results belong exclusively to two or three types, viz., geodic clayey kunkur (analogous to the septaria from which the so-called Roman cement is made) and the tufaceous and semi-tufaceous stones containing a large percentage of silicates. I may, however, mention that other types of hydraulic stone may possibly be found hereafter, but it is probable that the specimens sent to me would only exceptionally include any found not to yield a slaking lime. The few really good stones which I have found have been sent to me either without remarks or with remarks that they are bad or inferior, and I should not be surprised if a large number of cement-stones were discovered if *bad* limestones were specially required from the Indian subordinates who possess a knowledge of local mineral products.

When the physical characters of a limestone, or its physical character combined with the amount of silicates, indicated that it possessed hydraulic properties in a notable degree, the specimen was burnt. Where numerous investigations are carried on, an assay furnace with a muffle would be very useful for burning a number of small specimens at a time, but, under the circumstances of the present experiments, I found a furnace of the following construction to answer well:—

The furnace was 13 inches square in horizontal section, and 2 feet 8 inches high from the fire-bars to the top, exclusive of the ash-pit. It was closed by a lid of iron, faced with clay and paddy husk, working on hinges, and readily lifted by means of a pulley overhead and a counterpoise. At 8 inches above the fire-bars the furnace was divided vertically and equally into a back grate, for the reception of limestone and into a front firespace. The floor of the grate was formed by iron bars or a perforated fireclay plate, the front by a grating of half inch square iron bars; these require renewal after about a dozen burnings.

The grate was 1 foot 4 inches high, just above it was the flue. By this contrivance the limestone could be kept in its place while subjected to a red heat for any length of time.

The fuel used was coke and charcoal loaded at the top. The fire was usually lit at 5 P. M. and kept low all night; in the morning it was al-

lowed to burn well till 5 P. M. when it was let down; next morning the kiln was cool enough for the lime to be drawn.

I usually worked two furnaces; in each were three specimens of limestones separated from one another and from the walls by terrace tiles; above the limestone, specimens of puzzolana could be burnt.

When the lime was drawn, a sample was tested by the calcimeter, and if it contained not more than 5 per cent. of carbonate, was considered well burnt. It was powdered in an iron mortar, passed through a sieve of 30 meshes to the inch, slaked and finally reduced to paste. A portion of the paste was pressed into a small chatty (of 2 inches diameter) and immersed in water. The remainder was mixed with an equal volume of sand, and with this mortar pairs of bricks were joined and standard brickets moulded. If the specimen was obviously a cement stone, its adhesive strength was tested without sand being used.

The tests for setting were made by means of loaded needles—

A.	A needle of $\frac{1}{12}$ inch diameter at the point loaded with			$\frac{1}{4}$ lb.
B.	Vicat's needle $\frac{1}{24}$ inch	do.	do.	10$\frac{1}{4}$ oz.
C.	A needle of $\frac{1}{24}$ inch	do.	do.	1 lb.

The first and third were very useful for limes showing an extreme of fatness or hydraulic energy, and were found to give results consonant with those of Vicat's needle. Thus a lime supporting Vicat's needle after six days' immersion would usually support needle A in three days and needle C in nine days.

The adhesive strength test was also of great practical value. The pairs of bricks joined with a mortar of lime paste and sand in equal parts were immersed at once and tried after four weeks, and after one week if strongly hydraulic. I found that the addition of an equal quantity of sand obviated some failures in adhesion, while it did not detract perceptibly from the strength attained in four weeks. It was not however necessary in those limes which contained so much silicates as to be natural cements.

The system on which limes were divided by Vicat according to their rapidity of setting under water requires some modification before it can be applied to the case of Indian limes. The following table shows the division I have found most applicable:—

Quality.	Slaking.	Setting under water Vicat's needle.	Adhesive strength lbs. per square inch after		
			1 Day.	1 Week.	1 Month.
Fat, ...	Energetic; volume increases to 2 at least; volume of paste 1½ to 1¾,	Never sets and will be washed away in time if the water is renewed,	..	..	..
Meagre, ...	Energetic, but the volume increases to not more than 1¼,	Never satisfactory,	..	..	..
Slightly hydraulic,	Energetic; volume increases to 1½ or 2,	15 to 30 days, ..	..	2 lbs.	5 lbs.
Fairly hydraulic,	Do. do., ..	10 to 15 days, ..	..	2, 5 lbs.	5, 10 lbs.
Good hydraulic, ..	Languid; volume increases to not more than 1½, product lumpy,	5 to 10 days, ..	2 lbs.	5, 10 lbs.	10, 20 lbs.
Strongly hydraulic,	Hardly slakes unless powdered previously. Does not heat much,	2 to 5 days, ..	2,3 lbs.	10,15 lbs.	20,30 lbs. equal to the best bricks.
Cement, ...	Little or no heat even when powdered,	Less than 1 day,	3,5 lbs.	Do.	Do.

It should be observed that a lime may be meagre and yet hydraulic; the meagreness arises from a large quantity of inert silicates besides the small quantity which are active.

[In the original Report is a long and very complete descriptive list of specimens of limestones sent for examination, 511 varieties from the P. W. D. officers of the Madras Government, and 92 sorts sent by the Madras Railway Company and Madras Irrigation and Canal Company: and also a summarized description of these limestones. It would take up more space than can be afforded in this periodical to publish these descriptive lists, but they can be consulted by those interested in the subject and requiring detailed information on the qualities of the Madras limestones in the "Proceedings of the Madras Government, Public Works Department, 10th December, 1874." A copy of these Proceedings is kept in the Thomason College Library, Roorkee.—Ed.]

Abstract of Limestones examined.

District.	Perfectly fat.	Fat or slightly hydraulic.	Fair to good hydraulic.	Strong hydraulic.	Total.
Coimbatore, ...	..	36	1	4	41
Malabar, ...	..	2	..	..	2
Salem, ...	7	31	3	..	41
Tanjore, ...	3	22	6	..	31
Madura, ...	8	41	4	1	54
Tinnevelly, ...	..	18	3	..	21
Trichinopoly, ..	3	45	1	(2?)	51
South Arcot, ...	..	9	1	..	10
Chingleput, ...	1	11	2	..	14
North Arcot, ...	..	50	3	..	53
Nellore, ...	..	16	..	..	16
Vizagapatam, ..	..	18	1	..	19
Ganjam, ...	6	18	5	1	30
Bellary, ...	1	88	2	..	91
Cuddapah, ...	..	46	..	..	46
Kurnool, ...	..	13	2	..	15
Kistna, ...	..	3	1	..	4
Godavery, ...	..	17	1	..	18
Total, ...	29	484	36	8	557

Thus out of 557 limestones only 44, or about 8 per cent., promised to be more than slightly hydraulic.

In concluding this article, it may be useful to give a specimen of the system of classification adopted by M. Vicat in his Statistical Researches on Limestones. These tables, comprising the results obtained in the examination of 10,000 specimens (made in 1833—45), are drawn up in the following manner:—

Department.	No.	Color.	Texture.	Geological formation.	Insoluble. Per cent.	Insoluble. Quality.	Magnesia.	Classification.
Orne	96	Pale yellow ...	Very coarse.	Middle oolite ...	1·5	Clay	...	Fat.
Do. ...	92	Milk and Coffee.	Sub-compact.	Do ...	8	Do.	...	Slightly hydraulic
Do. ...	90	Buff ...	Chalky ...	Middle tertiary.	15	Do. ... ... (carbonaceous)	...	Hydraulic.
Do. ...	99	Do. ...	Do. ...	Middle oolite....	23·5	Clay	...	Intermediate.
Do. ...	91	Earthy yellow ...	Do. ...	Middle tertiary	26·5	Do.	...	Cement or intermediate.
Do. ...	89	Buff ...	Do. ...	Do. ...	31·5	Do.	...	Cement.
Do. ...	95	Reddish grey ...	Sub-compact.	Middle oolite....	22	Sand	...	Very meagre.
Do. ...	94	Dirty white ...	Coarse ...	Do. ...	33·5	Sand and a little clay ...	...	Valueless.

It has been seen (page 395), that Indian limestones give very different results; 20 per cent. of sand or other more or less inert silicates affect very slightly the "fat" character of the limestone, and the best stones examined have been those containing 40 per cent. and upwards of silica.

E. N.

(Extract from) Order on above Report, 10th December, 1874, No. 3468.

His Excellency the Governor in Council is much indebted to Surgeon-Major Nicholson for this clear and valuable Report, which will afford to all Executive Officers and members of the Department information, from which it is anticipated that a marked improvement in the selection and preparation of cements and mortars for different descriptions of public works will result. The remarks on pages 396 and 397 will be especially deserving of attention whenever it may be desirable or necessary to obtain cement stones for special work, while the paragraph (*vide* page 391) on the means of revivifying Portland cement, will be of practical utility to all who may require to use this material, though it may be expected that very generally District Officers will find close at hand the means of preparing a cement possessing all the more valuable properties of Portland, and obtainable at a small fraction of its cost.

No. CLXXVIII.

CONCRETE DAM FOR GEELONG WATER-WORKS.

[*Vide* Plates LII., LIII.]

By G. Gordon, Esq., *M. Inst. C.E., Chief Engineer, Victorian Water Supply.*

Dated Melbourne, 5th August, 1875.

It became necessary two or three years ago to construct a new reservoir for the supply of Geelong with water. The only favorable site which offered itself was on the "Stony Creek," a mountain stream flowing through a steep rocky country in the Steiglitz ranges. It was resolved to close one of the gorges through which the stream passed, and as there would have been great risk of failure if an earthen dam were constructed, owing to the steepness of the rock forming the sides of the gorge, I determined to construct a masonry dam on the French system of equal pressures. The formula used by Messrs. de Graeff and Delocre, was modified, however, so that the limiting pressure (8,000 lbs. per square foot) was the pressure on a surface perpendicular to the rear slope of the dam, and the resultant of the pressures was made to cut the base of any horizontal section of the dam within the middle third of that base It was intended to build the dam in courses of rubble stone curved in the manner shown by dotted lines on the section, (*Plate* LII.,) so that the beds should be nearly perpendicular to the directions of the pressures. Owing chiefly to the scarcity of masons, but also to a possible difficulty of getting a sufficient quantity of suitable building stone, the dam was built of concrete instead of masonry. The proportions at first adopted were:—

Broken sandstone, 3″ gauge	1
" " 2″ "	2
" " 1″ "	1
Sand, ...	1
Portland cement, ...	1

but this concrete was considered too coarse, and it was likely to be porous. After several trials the following was adopted:—

Broken stone, 2″ gauge, ...	3¾
Screenings, ...	1¼
Sand, ...	1¼
Cement, ...	1

This formed a thoroughly sound, compact and water-tight mass, but great care in mixing it was essential. The cement and sand were first thoroughly mixed and made into mortar, and the other materials after being well wetted were added gradually. The mixing was at first done by manual labor, but afterwards it was performed in an annular trough by means of small ploughs fixed in frames under a beam working on a pivot, and supported at the edge of the trough on rollers. This was worked by a horse at each end of the beam, and the concrete when mixed, fell through a trap door in the bottom of the trough, and was lowered on to the work in boxes, which travelled on hard wood rails laid on the steep slope of the bank. As the locality was very difficult of access, this apparatus was roughly made on the spot of bush timber.

The dam is curved on the plan to a radius of 300 feet. The front face is vertical for 30 feet from the crest, and it then has a slight batter, as shown on the cross section (*Plate* LII.) Both front and rear surfaces were plastered with cement mortar of 1 cement to 2 sand. The greatest height of the work is 67½ feet; the height above the old bed of the creek where the scour is placed 55 feet. The outlet pipe is 9 feet above the scour. The width at top is 2 feet 6 inches, under the coping which, flush in front on account of the action of the waves has a projection of 3 inches over the back of the dam. The width or thickness at the level of the scour is 38 feet 9 inches, and of the foundations 61 feet. There are two valve houses also built of concrete. The work was carried on as nearly as possible without intermission, except at night and on Sundays. The concrete was brought up in layers of 7 inches in thickness well rammed, the surface being swept, watered and mopped over with cement grout before each layer was put on. The rock was grooved on the vertical faces and washed with cement grout. The work was begun in January 1873, and finished up to the coping in June 1874. The total contents are 5,096 cube yards, the total cost £17,306, including all preliminary and other expenses, plant, tools, &c., but not the Engineer's salary. Cement cost 31*s.* per barrel;

sand, 6*s.* per cubic yard; metal, including quarrying 4*s.* 6*d.* to 6*s.*; carting, mixing and placing concrete, done by day labor, cost about 10*s.* per cubic yard; labourers wages were 6*s.* 6*d.*; plasterers 8*s.*; masons 10*s.*; hire of two horses and driver 20*s.* per day.

The dam is perfectly tight, but there is a very slight soakage through the crushed rock under the foundations when the reservoir is full. The reservoir contains 22¼ millions of cubic feet of water. As there is another reservoir on the same creek higher up, it was not necessary to provide much space for flood-water. Any surplus water will pass over the middle part of the dam, which, for a length of 30 feet is one foot lower than the sides, and extreme floods may pass over the whole length in a thin sheet without injury to the dam. There is a cage or grating in front of the outlet pipe (not shown in the Plates) which is lifted for cleaning by a winch placed on the top of the dam. The outlet pipes are 24 inches cast-iron pipes bedded in the concrete. Each has a valve at the outer end. A water cushion is formed below the scour pipe and overflow by a small dam lower down in the creek. The outlet pipe is continued by the cast-iron main leading to the town.

G. G.

CONCRETE DAM FOR GEELONG WATER WORKS.

(Front Elevation).

Scale 80 feet = 1 inch.

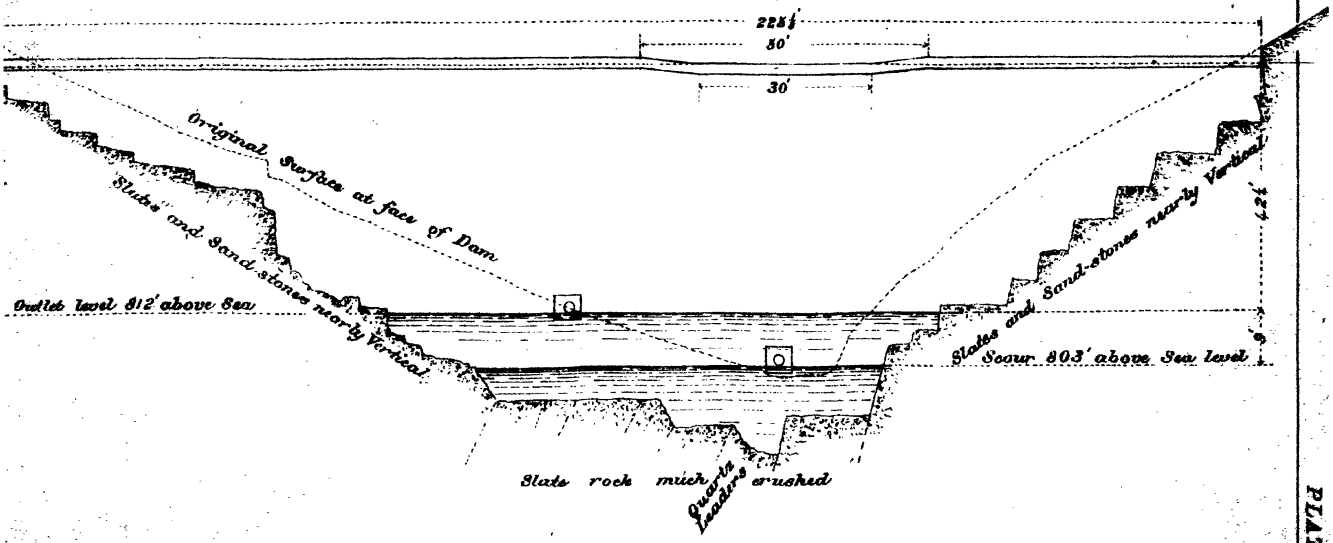


PLATE I

No. CLXXIX.

FORM OF CHANNEL OF CONSTANT MEAN VELOCITY.

Remarks on a Paper entitled "Form of Channel of Constant Mean Velocity," (No. CLXI., Vol. IV., Professional Papers on Indian Engineering, [Second Series]). By E. Gramatzky, Esq., *Executive Engineer, D. P. W., Mysore.*

In Part 17 of the Second Series of Professional Papers on Indian Engineering, appeared a Paper on the "Form of Channel of Constant Mean Velocity," which contains some very remarkable results. It professes to solve the following problem:—

"To calculate such a contour to the cross section of a channel, that for all depths (x) of water running in it with a given declivity (p), the mean velocity (v) of the current shall be constant, and equal to a given quantity assigned."

The equation from which this contour is to be calculated is:—

$$v = n\sqrt{p\frac{s}{c}} \quad \text{.....(1).}$$

Whence

v = given velocity,
n = co-efficient of discharge, } constants.
p = given declivity,

s = area $= 2\int_0^x y\,dx.$

c = perimeter $= 2\int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\,dx.$

Squaring equation (1) and transposing, we obtain

$$\frac{v^2}{n^2p} = \frac{s}{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$

After a lengthy investigation, into the details of which I do not intend entering, the following result is given on page 214, under the head "Recapitulation of results."

$$\frac{s}{c} = \beta \frac{\phi}{1+\phi}$$

entering the value of β, viz., $\frac{v^2}{n^2p}$ into this equation, it becomes—

$$\frac{s}{c} = \frac{v^2}{n^2p} \frac{\phi}{1+\phi}$$

and putting this value of $\frac{s}{c}$ in equation (2), we have

$$\frac{v^2}{n^2p} = \frac{v^2}{n^2p} \frac{\phi}{1+\phi}$$

$$1 = \frac{\phi}{1+\phi}$$

$$1 = 0,$$

which clearly proves the incorrectness of the results obtained.

It is moreover easy to show that a contour, fulfilling the given conditions, does not exist. Taking again equation (2), and remarking that s and c, the area and its perimeter, are not independent of each other, but that the latter quantity (c) is a function of the former (s) and therefore may be designated by $f(s)$, we obtain—

$$\frac{v^2}{n^2p} = \frac{s}{f(s)}$$

$$\frac{v^2}{n^2p} f(s) = s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

If now s diminishes without limit, the left side of the equation (3) must also diminish without limit, and as $\frac{v^2}{n^2p}$ is constant, $f(s)$ must diminish without limit, so that when $s = 0$, $f(s)$ also must be equal to zero *But the area and its perimeter can only vanish simultaneously, when* (x) *and* (y) *become zero simultaneously.*

Putting $s = \int_0^x y dx$ and

$c = \int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\, dx$ into equation (2), we have

$$\frac{v^2}{n^2p} = \frac{\int_0^x y dx}{\int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\, . \, dx}$$

$$\frac{v^2}{n^2p}\int_0^x \sqrt{1+\left(\frac{dy}{dx}\right)^2}\,dx = \int_0^x y\,dx.$$

Differentiating with regard to x we obtain

$$\frac{v^2}{n^2p}\sqrt{1+\left(\frac{dy}{dx}\right)^2} = y.$$

$$\frac{v^2}{n^2p}\,\frac{dy}{\sqrt{y^2-\frac{v^4}{n^4p^2}}} = dx.$$

Integrating this equation without assigning any limits, as we only search for the relation between x and y, it becomes

$$x = \frac{v^2}{n^2p}\,.\,\text{hyp. log.}\left\{y+\sqrt{y^2-\frac{v^4}{n^4p^2}}\right\} + \text{C}.....(5).$$

In order to find C, substitute the simultaneous values $x = 0$; $y = 0$ in equation (5), which gives

$$0 = \frac{v^2}{n^2p}\,.\,\text{hyp. log.}\left\{\frac{v^2}{n^2p}\sqrt{-1}\right\} + \text{C}$$

$$\text{C} = -\frac{v^2}{n^2p}\,\text{hyp. log.}\left\{\frac{v^2}{n^2p}\sqrt{-1}\right\}$$

putting the value of C into equation (5), we obtain

$$x = \frac{v^2}{n^2p}\,\text{hyp. log.}\left\{\frac{y+\sqrt{y^2-\frac{v^4}{n^4p^2}}}{\frac{v^2}{n^2p}\sqrt{-1}}\right\}$$

From this equation, it is evident that x is imaginary for every real value of y, except zero, and therefore no contour can exist which fulfils the required conditions.

E. G.

NOTE *on Mr. F. E. Rose's Paper No. CLXI. (Form of Channel of Constant Mean Velocity), and Mr. E. Gramatzky's Paper No. CLXXIX., (Remarks on the former).*

By CAPT. ALLAN CUNNINGHAM, R.E., *Hony. Fell. of King's College, Lond.*

There are five serious typographical errors in (Mr. Rose's) Paper No. CLXI., (3 on page 213, and 2 on page 214, see List given below), and several unimportant ones. These being corrected, there appears to be no mistake either in the principle or details of the investigation of that paper.

It appears however to have been overlooked that the quantity

$$\left\{\frac{1}{4}\left(\frac{1}{\log^{-1} ax} + \log^{-1} ax\right)^2 - 1\right\}$$

is a *perfect square;* by extracting the square root of which Results (B), (C), and the value of ϕ (*see* Paper CLXI.) are much simplified. But the whole of the Paper would be much simplified by using exponentials (e^x) instead of the comparatively unfamiliar inverse logarithmic form ($\log^{-1} ax$); thus the Results (A), (B), (C), of that Paper are *much more simply* written,

Equation of Curve, $$y = \frac{\beta}{2}\left(\varepsilon^{\frac{x}{\beta}} + \varepsilon^{-\frac{x}{\beta}}\right) \quad \text{(A)}.$$

Area, $$s = \beta^2\left(\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}}\right) \quad \text{(B)},$$

Perimeter, $$c = \beta\left(\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}} + 2\right) \quad \text{(C)}.$$

and it is then at once seen from (A) that the curve denoted is a *common catenary.*

The Problem proposed in Paper CLXI. may be thus stated as a pure mathematical Problem,

"To determine a figure symmetric about a vertical axis such that the ratio $\frac{\text{Area below any horizontal line}}{\text{Perimeter below same line}}$ = a constant quantity $\frac{v^2}{n^2 p}$ or β".

It must be conceded that the investigation of Paper CLXI. solves this Problem probably as far as it is capable of solution, and does really lead to the Results (A), (B), (C).

Unfortunately the Result is not really *generally true,* and is indeed true only under such circumstances as to be of little practical use. In fact the fundamental equation gives

$$\beta = \frac{v^2}{n^2 p} = \frac{s}{c} = \beta\,\frac{\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}}}{\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}} + 2} \quad \text{by (B), (C) above,}$$

Whence $$1 = \frac{\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}}}{\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}} + 2}$$

which is obviously *not generally true** (*i. e.*, not for all values of x).

* As shown in Mr. E. Gramatzky's Paper above.

But it is true (in the limit)* *when* (x) *is very large compared with* β, for in this case

$$\frac{\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}}}{\varepsilon^{\frac{x}{\beta}} - \varepsilon^{-\frac{x}{\beta}} + 2} = \frac{1 - \varepsilon^{-\frac{2x}{\beta}}}{1 - \varepsilon^{-\frac{2x}{\beta}} + 2\varepsilon^{-\frac{x}{\beta}}} = 1 \text{ nearly, since } \varepsilon^{-\frac{x}{\beta}} \text{ is infinitesimal.}$$

Thus the cross-section indicated satisfies the required condition *only when the depth* (x) *is very large compared with the breadth* (2β), and unfortunately these circumstances are the least useful in practice.

The latter Paper No. CLXXIX. (Mr. Gramatzky's) is important in drawing attention to the fact that the solution given is of little practical use, but the strictures therein are rather too strong, as the Problem is certainly correctly solved in Paper CLXI. probably as far as it is capable of solution.

The final conclusion in Paper CLXXIX., that "no curve can possess the required property" is not warranted by the investigation given.

The investigation by which this is attempted to be proved virtually involves the *à priori* hypothesis, that the curve required is some one single *continuous* curve.

[This assumption is virtually involved in the manner in which the limits of integration are introduced in determining the constant C, as will be easily understood by any one who has a sufficient knowledge of infinitesimals].

All that can be said to be fairly proved—in consequence of this assumption—is that—

"No one single *continuous* curve can possess the required property".

This proof might readily be extended to show that—

"No figure made up of portions of *different* curves—(excepting the case where part of the wetted border is a horizontal straight line)—can possess the required property".

And this excepted case is the very one required. But the fact is that this is already implicitly proved in Paper No. CLXI., where it is shown that the figure required must possess a horizontal portion (at the bed) of length 2β as well as the curved portion.

Errata in Mr. F. E. Rose's Paper No. CLXI.

Page 213, line 7 from foot, *for* $\int \sqrt{1 + \frac{y^2}{\beta^2} - 1}, \quad \frac{dy}{\sqrt{\frac{y^2}{\beta^2} - 1}}$

read $\int \sqrt{1 + \frac{y^2}{\beta^2} - 1} \cdot \quad \frac{dy}{\sqrt{\frac{y^2}{\beta^2} - 1}}$

Page 213, line 6 from foot, and 2 from foot, *for* $- \log^{-1} ax$, *read* $+ \log^{-1} ax$.

„ 214, line 7, *for* $\left(\frac{1}{\log^{-1} dx} + \log^{-1} dx\right)$, *read* $\left(\frac{1}{\log^{-1} ax} + \log^{-1} ax\right)$.

A. C.

* This has been overlooked in Paper No. CLXXIX.

HYDRAULIC EXPERIMENTS AT ROORKEE.

By Capt. ALLAN CUNNINGHAM, R.E.,

Hony. Fellow of King's College, London.

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[*N.B.*—The Numbers refer to the Articles.]

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CHAPTER I.

INTRODUCTORY.

1. Introductory.—The most important quantity that admits of calculation in Hydraulic Engineering is the Total DISCHARGE of a body of water through a given transverse section; and in artificial channels—such as Canals—it is desirable that this should be calculable with some accuracy.

"Discharges" of large Canals and Rivers are being repeatedly measured, but can any reliance be placed on the numerical values of the so-called "Discharges"? What is the TEST that the numerical values for "Discharge of large bodies of water, as now obtained are correct? As a matter of fact, "Discharges" are now obtained by calculation from formulæ, the functional form of which is based on hypotheses of motion of water admittedly incorrect, and involving "constants" whose numerical values, have as yet been determined solely from experiments on very small bodies of water, *e. g.*, in pipes and in *small* artificial channels.

[The only TEST—and that a very rough one—at present applied (as far as the author knows) in large Canals, is that of measuring the "Discharge" (in the ordinary way) of a Main Canal at a moderate distance above a point where it gives off several large Branches (vern. "Rajbahas"), and also of the separate Branches and Main Canal below this point, and *comparing the sum of the latter with the former Results.* This Test is one that could be applied by any Executive Engineer. It has, however, either never been seriously undertaken on such a large scale as to amount to a real experimental verification of existing formulæ, or if undertaken the Results have not been published (as far as the Author knows)].

2. Present state of knowledge.—Three extensive series of Hydraulic Experiments have been made of recent years,—

1°. On the largest scale, (*i. e.*, on motion of mighty rivers) in 1850-61, on the Mississippi and its affluents.

2°. On the small scale, (*i. e.*, on motion of small bodies of water) in 1855-60, in France, by Messrs. Darcy and Bazin.

3°. On the largest scale, (*i. e.*, on motion of mighty rivers) in 1870 on the Paraná, Uruguay, and La Plata, by Mr. Révy.

[For brevity, the Reports* of these Experiments will be styled simply 1°, the Mississippi Report ; 2°, the Darcy-Bazin Report ; 3°, the Révy Report].

These three Series of Experiments are the first really accurate and *sufficiently extensive* Experiments on flow of water. They have added much to our knowledge of Hydraulics, and yet left much unknown.

The French Experiments are—it is believed—ample as regards flow of very small bodies of water: (the channels experimented on not exceeding 2 mètres in breadth).

The Mississippi and Paraná Experiments clearly show that Results derived solely from experiments on small bodies of water are not safely applicable to large bodies of water without preliminary verification.

Unfortunately the Mississippi and Paraná Experiments were chiefly on motion of too complex and tumultuous a character to admit of unravelling from them the laws of fluid motion: and many of the results therein assumed as *general* are certainly *only particular* (or local).

[These remarks apply especially to the Paraná Experiments : the fluid motion in many of which is enormously complicated by the presence of a variable tide, so that few of the Paraná Experiments are *fairly intercomparable*, and many of the Results are really *only local*, not general. This will appear in the sequel].

3. Experiments on large uniform Canals desirable.—The sort of Experiments now wanted are an extension of the French Experiments to large bodies of water *in uniform motion in regular channels.*

It is—in the Author's opinion—very little use experimenting at present on the excessively complex motion in large rivers, until the comparatively simple case of STEADY UNIFORM MOTION in a large uniform channel—such as can usually only be obtained in artificial Canals—is better understood.

4. Opportunities in India.—The presence of many large Canals points to India as presenting unusually favorable opportunities for prosecuting such experiments *with a fair expectation of a useful result.* Experiments on a limited scale have been carried out by many of the regular

* i. Report upon the Physics and Hydraulics of the Mississippi River, &c., &c. By Captain A. A. Humphreys, and Lieutenant H. L. Abbot, U. S. Army. Phil. 1861.

ii. Récherches Hydrauliques enterprises, par M. H. Darcy, continuées par M. H. Bazin. Paris, 1865.

iii. Hydraulics of Great Rivers. The Paraná, the Uruguay, and the La Plata Estuary. By J. J. Révy. London and New York, 1874.

[As these are large and expensive Works, it may be mentioned that there are Notices of the two first in the "Professional Papers on Indian Engineering," Nos. CLXXXVII. and CXCVII. of FIRST SERIES (by the late Lieut.-Col. J. C. Anderson, R.E.), and of the last in the "Pioneer" Newspaper of 24th April and 20th May, 1875 (by J. Elliott, Esq. M.A.)].

Canal officers, but partly from want of special funds, and partly from want of leisure, these experiments of individuals have necessarily been of a desultory character, and limited in number: moreover, not having been published, they are practically buried.

Experiments on a considerable scale were projected in 1866-67 to be performed on the Ganges Canal, at or near Roorkee, but by some extraordinary fatality every officer* connected with them died before any considerable progress was made. It is believed, that no report was printed, and it seems impossible now to ascertain what was actually done.

5. Object of the present Experiments.—The object of the Experiments about to be described, was primarily that explained, (Art. 3,) as now desirable, viz., to test the applicability of the Results of the American and French Experiments *to large bodies of water in regular channels.*

Results of great interest—beyond the important practical one of affording a TEST of existing Discharge-Formulæ—might be expected to accrue from the sort of observation proposed (Art. 8) if the Experiments be made on a sufficiently extensive scale, prolonged over a long period, and under varied conditions.

The present Experiments—lasting only four months—are of course *only a small beginning* in this direction.

PRESENT REPORT. The pages following contain simply a Report of the Experiments themselves, and a discussion of the conclusions to be drawn from them. The *Detailed* Results are of necessity published in the form of TABLES, the examination of which cannot fail to be a tedious task to the reader, but this is inseparable from all experimental researches. Graphic illustrations have been largely used to save the eye. The present Report is strictly *one of Experiments:* no mathematical investigation is introduced, except where suggested by the Experiments themselves, either as the conclusions to be drawn from the Experiments, or as elucidating the Experiments.

A tolerably full SUMMARY of the Results is given in Chapter V., from which the scope of the work done can be gathered at once. There is also a very full Table of Contents at the beginning to facilitate reference.

6. Conduct of the Experiments.—These Experiments were conducted by the author, *as a volunteer* during the cold weather of 1874-75,

* The late Lieut.-Col. J. Dyas, R.E., Lieut. J. Carroll, R.E., Lieut. P. Cotterill Smith, R.E.

on the Ganges Canal close to Roorkee: Government providing the necessary funds.

The Staff for performing the Experiments consisted of two Europeans, (an Overseer* of the Public Works Department, and a Non-Commissioned Officer† temporarily lent from the Sappers and Miners), and eight native boatmen, and "classies."

The Field-work was begun‡ on 9th December 1874, and was continued with slight intermissions caused by rain, high wind, &c., daily (on week days) up to 15th April, 1875.

The whole of the responsible *observations* of every sort—whether sounding, measuring distances, calling out instant of passage of floats, use of chronometers, &c.—and also the computation attending the reduction of the observations were (with the exception of a few done by the Author himself) performed *by the two Europeans*, trained in the first instance by the Author.

After overcoming the difficulties inseparable from a novel work, the Author's share in the work was limited to superintendance, and to direction of the reduction of the field-work, and collating the Results.

7. Difficulty of the work.—Many difficulties, some practical, some due to climate, were met with.

The first part of the season was spent *simply in learning* how to do the Experiments with tolerable accuracy and convenience.

The season available for such Experiments is practically limited to the short cold weather, and even this is curtailed by the occasional prevalence of high wind, rain, &c.

The use of the Canal as a Navigation-Canal sometimes seriously interfered with the work, the command of the Ropes stretched over the water being insufficient to let barges pass: the Ropes and Chains were several times broken by passing barges, which caused great delay.

The constant variation of level of the Canal (from day to day) was a great obstacle to the continuity of fairly comparable observations; it will be seen hereafter, that in consequence of the "UNSTEADY MOTION" of the water, the AVERAGE VELOCITIES of the different "stream lines" (taken from a very large number of observations under similar external condi-

* Sergeant J. Warburton, R.A. † Corporal H. Rowe, R.E.

‡ This was the day the Overseer joined the work: it is to be regretted that the Overseer was not provided earlier, as much of the valuable cold weather was thus lost.

tions of wind, depth, &c.,) are the *only quantities fairly comparable* with one another.

With varying external conditions (of wind, depth, &c.), it is difficult to secure a sufficiently large number of observations under similar external conditions on each stream-line, to yield a fair *average value* of the velocity in each stream-line.

[It will be seen in what follows, that in several of the Velocity-Curves, *each* ordinate (or velocity) is the Mean of 60 separate measurements].

The great monotony of the field work (which will be understood hereafter) constitutes a serious difficulty in the way of interesting intelligent men in the work.

8. Description of Test proposed.—The TEST mentioned in Art. 1, is at best an imperfect one: the only satisfactory TEST of existing "Discharge-formulæ" would be to measure the Discharge by some independent (and admittedly accurate) method at a few selected places, and compare the Results with those of the existing formulæ.

[To avoid circumlocution, the following definition of the term "velocity" is premised.

DEF. The term "velocity" will be usually used in this Paper (for shortness) to express not the "actual velocity" of fluid at a point, but only the *resolved part of the actual velocity parallel to the axis of the stream.*

This is the only part of the actual velocity of much use in questions of "Discharge," and is in fact the sense in which the term is used in all works on practical Hydraulics—though not distinctly explained].

The most direct—and perhaps only satisfactory—way of accurately measuring the DISCHARGE of a *large* uniform channel—too large to be either received into a Tank, or passed over a weir—would appear to be as follows:—

Imagine a cross-section of a Channel divided by horizontal and vertical planes into a great number of small rectangles, and let the "velocity" of the fluid at centre of each rectangle be *separately measured.* Then if

v = 'velocity' at centre of any rectangle.

a = area of type-rectangle,

Partial discharge through type-rectangle = $v\,a$ *nearly.*

Hence if due allowance be made for the partial discharges through the triangular or curved areas at the boundary of the channel,—which may also be included under the same type (va),

$$\text{Total Discharge} = \Sigma\,(v\,.\,a), \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (1).$$

If the planes of division be so numerous,—or the rectangles so small,—that the "velocity" through all parts of each particular rectangle does not vary much, the Result (1) will be of a considerable degree of accuracy,—(if the velocity-observations themselves be accurate).

The comparison of Results so obtained with those given by existing formulæ, would be the TEST of the sufficiency of the latter.

The present experiments were all directed to this end, viz, to *measurement of "velocity"* at very numerous points in a cross-section.

9. VELOCITY-CURVE, VELOCITY-SURFACE.—To avoid circumlocution, the introduction of these terms is convenient.

Imagine perpendiculars erected at every point of any cross-section of a channel, *each proportional to the "velocity"* of the fluid at the point. Their extremities will trace out a certain surface, which will be called the VELOCITY-SURFACE at that section.

It is evidently by its ordinates a 'graphic representation' of the 'velocities' at every point of the cross-section.

The plane curves which are the sections of this Surface by horizontal and vertical planes, will be called Horizontal Velocity-Curves, and Vertical Velocity-Curves: they are evidently 'graphic representations' of the 'velocities' past horizontal and vertical Lines of the cross-section.

The areas of the Horizontal and Vertical Velocity-Curves evidently represent the (superficial) Discharges past those Lines, and the Volume of the Velocity-Surface evidently represents the (cubic) Discharge through the whole cross-section.

Great use will be made of these Curves in the Sequel.

10. Scene of the experiments.—The experiments were performed in the Ganges Canal, which, in the neighbourhood of Roorkee, presents unusually favorable opportunities for such experiments in the occurrence of *a straight reach of six miles* of comparatively uniform section, from Dhanourí to Roorkee—*see* Sketch Map (*Fig.* 1)—the only obstructions in the current above the Solání Aqueduct being two narrow piers of two bridges at Pírán Kalliar and Mahewa.

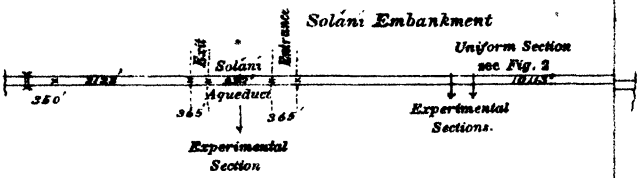
This six-mile reach comprises three descriptions of channel, viz.,

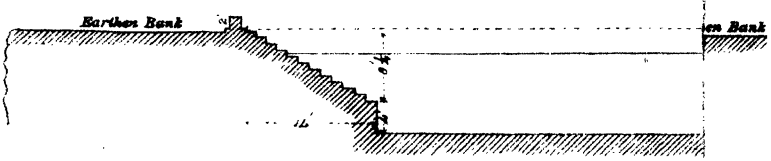
i. *Trapezoidal Channel*, in earth, 3 miles long, 150′ average bed width.

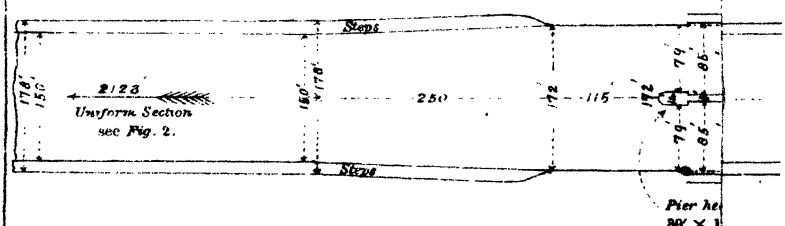
ii. *Trapezoidal Channel*, masonry sides (steps), clay bed, 2 miles long, 150′ bed-width.

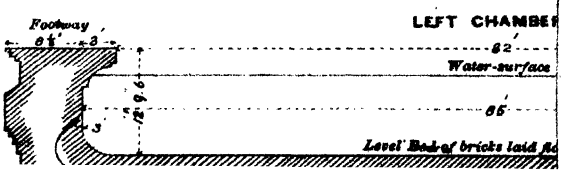
iii. *Rectangular Twin Channels*, in masonry, 932′ long, each 85′ wide.

PLATE I.


Solani Embankment
Exit
Entrance
Solani Aqueduct
Uniform Section see Fig. 2
350'
365'
365'
Experimental Section
Experimental Sections.


Earthen Bank
Earthen Bank


Steps
212.5
Uniform Section see Fig. 2.
250
115
Steps
Pier he
30' × 1


Footway
LEFT CHAMBE
Water-surface
Level Bed of bricks laid fl

iv. *Trapezoidal Channel*, same as ii, ½-mile long.

Thus the *same body of water* passes successively through these different channels, each of which is nearly uniform throughout its own length, but differing from each other in material, figure of cross-section, and width—thus presenting a very favorable locality for Hydraulic Experiments.

It should be remarked, that the Ganges Canal is generally highly charged with silt, which is of course variable in amount, according to the state of the Ganges from which the supply comes.

[Silt-measurement was not attempted in the present Experiments. Accurate silt-measurement is a matter of considerable difficulty, and in the present state of Hydraulic Science—little use could be made of the Result beyond simply recording it].

i. *Dhanouri to Mahewa Bridge* (about 3 miles).—An earthen trapezoidal channel nearly uniform for about 3 miles. No experiments were performed in this reach.

ii. and iv. *Mahewa Bridge to Roorkee Bridge* (about 3 miles).—The Canal is carried across the valley of the Solání River in a channel with masonry sides and a clay bed on the top of an earthen embankment.

Except where it passes over the Solání River,—viz., by the Solání Aqueduct, *see* iii. below,—the sides of the channel consist of two vertical masonry walls 150′ apart to a height of 4′ above the (original) level of the bed of the channel, surmounted by two flights of 12 masonry steps, each 14″ broad by 9″ high. On the top of the steps are low masonry parapets, which are herefore 178′—(14′ + 150′ + 14′)—apart in the clear. The whole of the masonry is plastered with fine smooth plaster.

The bed of the channel is of clay.

Fig. 2 shows the average section nearly uniform (as originally built) for 10,113 feet—commencing from 350′ below Mahewa bridge to 365′ above the Solání Aqueduct, and again for 2,123 feet—commencing from 365′ below the Solání Aqueduct to 350′ above the Roorkee bridge.

Thus the width of water-surface would vary in these reaches between

A minimum of 150′ when not more than 4′ deep.
A maximum of 168′ 8″ when at full depth (about 10′).

The flights of steps and the bed were originally built uniform throughout the lengths 10,113 feet and 2,123 feet mentioned: but in course of time the steps have subsided in some places, and the bed has been eroded irregularly.

To protect the bed, boulders have since been thrown in irregularly, and tolerably regular boulder and brick "bars" have been thrown across the bed where most eroded, the tops of which mark the mean level of the bed.

The general Result however is, that the original strict uniformity of the channel no longer exists, especially as regards the state of the bed.

iii. *Solání Aqueduct.*—The canal is here carried across the Solání river in a masonry Aqueduct 932′ long, divided into equal 85′ waterways by a central masonry pier 932′ long and 8′ wide—except at the two ends, (or pier-heads,) which are 14′ wide for a length of 30′.

The enlarged Plan (*Fig.* 3) of the Aqueduct and Approaches shows, with the help of the Table below, how the single waterway 150′ wide at bed —of section shown in *Fig.* 2—gradually widens to 172′ in the 250′ "Approach" to the Aqueduct, which width is continued uniform for 115′, when it is parted by the 14′ "Pier-head" into two equal 79′ waterways for a length of 30′; these are enlarged by equal 3′ off-sets on each side into 85′ waterways, which are carried *of the uniform section* shown in *Fig.* 4 *for a length of* 872′. The Exit below this is precisely similar to the "Entrance" and "Approach".

Description	Length	Waterway	Width of Waterway	Cross-Section	Sides
Solání Embankment, ...	10,113′	1	150′ at bed.	As in *Fig.* 2.	
Approach to Aqueduct,	250′	1	150′ at bed gradually increased to 172′ at bed.	Similar to *Fig.* 2.	Flights of 12 steps 9″ high, 14″ tread above 4′ walls.
	115′	1	172′.	Rectangular.	Vertical.
Solání Aqueduct, ...	30′	2	79′ each.	2 rectangles.	Vertical.
	872′	2	85′ each.	2 rectangles with rounded corners as in *Fig.* 4.	Vertical rounded at bottom, see *Fig.* 4.
	30′	2	79′ each.	2 rectangles.	Vertical.
Exit from Aqueduct,	115′	1	172′.	Rectangular.	Vertical.
	250′	1	172′ at bed, gradually diminished to 150′ at bed.	Similar to *Fig.* 2.	Flights of 12 steps 9″ high, 14″ tread above 4′ walls.
Solání Embankment, ...	2,123′	1	150′ at bed.	As in *Fig.* 2.	

The cross-section of either "Chamber" of the Aqueduct is seen (*Fig.* 4) to be a rectangle 85′ wide with the two lower corners rounded off 3′ each—so that the bed width is only 82′.

The sides are of brick masonry plastered,* and the bed is of *brick laid flat and grouted with mortar*, and is very regular throughout its length, being generally covered with a small irregular deposit of an inch or two of silt.

The public footways overhang the water 3′—as shown in *Fig.* 4—and are corbelled out from a height of about 8′ 3″ above the bed, so that the width of the *water surface* is of the full 85 feet width of the chambers only when not running deeper than 8′ 3″; when the water runs deeper than this, its surface-width is sensibly narrowed.

[This corbelling out prevents any velocity-measurements being effected nearer to the outer margins than 3 feet: this will be seen hereafter].

There is a STANDING GAUGE marked to decimals of feet, in the Left Chamber at the middle of the Pier.

11. *Experimental Sections.*—Four Sections in all were chosen for purposes of Experiment.

SOLANI AQUEDUCT.—(For description, plan and section, *see* Art. 10—iii, and *Figs.* 3, 4.)—The centre cross-sections of both Chambers were chosen as the principal Experimental Sections for following reasons:—

(*a*). They are at centre of a length of 872′—a *uniform*, nearly rectangular section, the bed of which is *remarkably even*—(this was verified by an extensive series of soundings,—*see* Art. 19; the maximum variation of level (due to silt) was found to be about 3″ in neighbourhood of these sections).

(*b*). There is a STANDING GAUGE at one of them showing the depth.

(*c*). The Discharge measurements by the Canal Officers in the neighbourhood have been executed at them for many years.

[It may be doubted whether the fundamental condition laid down in Art. 3, of "uniform motion in a symmetrical channel"—as alone suitable for Experiment—is realised at these two cross-sections at centre of channels which are quite uniform only for a length of 872′ (about 10¼ times their width), whilst the supplying and discharging channels are each *twice their width*. This is a point which can only be properly determined by actual experiment.

The Experiments may not—as far as yet carried out—conclusively show this, but the fair symmetry of the surface-velocity mean curves obtained, (*see Plate* IV., Art. 33), for these central sections warrants the belief that the motion across and in the neighbourhood of this section is *approximately that of a uniform channel of great length*].

* The left side of Left Chamber is *plastered with 'kunkur' lime plaster* (somewhat rough) *to full height*: the right side of Right Chamber, and both sides of central Pier are *plastered with smooth lime plaster to height* of 6′ only.

SOLANI EMBANKMENT.—Two sections at 2,860 feet and 3,195 feet, respectively, above the central pier of the Solání Aqueduct—(*see* Sketch Map, *Fig* 1,) were chosen as "Experimental Sections".

The Experiments executed at them were solely measurements of SURFACE-VELOCITY: these are described in Art. 34.

The "Average Cross-Section" *in the neighbourhood of the* Experimental Sections was obtained by sounding, as described in Art. 19, the Resulting Sections are figured along with the descriptions of the Experiments at them—Art. 34.

There was no Standing Gauge at these Sections: the nearest Standing Gauge was that in the Solání Aqueduct. This gauge was always read just before and just after each day's work. The 'gauge-depths' figured in the Tables of Results *all refer to this gauge.*

[The actual height of the water-surface *at the Experimental Section* with reference to the top of the highest step of the flights of masonry steps was also always recorded in the Field-book, both at beginning and end of each SET of Experiments, as a check on the work].

12. Instruments used.—In order to establish confidence in the Results of these Experiments, it seems advisable to explain in detail the Instruments and mode of observations used for measurement of velocity.

Many instruments have been at various times proposed for this purpose: they may be roughly classed as FIXED INSTRUMENTS and FREE INSTRUMENTS.

I. FIXED INSTRUMENTS.—Such are the Tachometer or Current-metre, Pitot's Tube, Hydrometric Pendulum, Water-lever, Water-vane, Hydraulic Balance, Rheometer, &c., &c., which *being fixed in a given position* measure directly or indirectly the current-velocity. Several of these are described in Weisbach's "Mechanics of Engineering", Vol. I., Art., 378, *et seq.*, and in the "Mississippi Report", page 202, *et seq.*

Most of these Instruments—except perhaps "Pitot's Tube" are open to numerous objections. "Pitot's Tube"—as improved by Darcy—has become almost classical from its nearly exclusive use in Darcy and Bazin's Experiments.

The delicacy of observation, however, requisite with all these Instruments—except the Current-metre—necessitates their being used from a very *steady temporary bridge,* the erection of which over a wide channel would of course be impracticable.

Elliott's and other "Current-metres" can be used *from a boat*, but the presence of the boat so greatly modifies the natural motion of the water, that good results could not be expected from them *within a distance of some feet below the boat's keel.*

[Some of the "Fixed Instruments" (*e. g.*, the Current-metre)—in consequence of being provided with a large "tail" which causes them *always to face the current* —measure (or are intended to measure) the ACTUAL VELOCITY of the fluid filaments passing them, and not merely the "velocity" as defined in Art. 8, viz., the resolved part of the actual velocity parallel to the axis of the stream; but this is on the whole rather a disadvantage (*see* Art. 8) than an advantage in their use].

For these reasons, the use of "Fixed Instruments" was entirely rejected in these Experiments.

[It may be remarked that for similar reasons they were entirely rejected in the Mississippi Experiments].

II. FREE INSTRUMENTS, or FLOATS.—By this term is meant any sort of "floating apparatus", which may for shortness be called a FLOAT, whether floating at the surface, or partly submerged—which is dropped into, and abandoned to the current. In a "uniform stream" all such objects acquire after a time a state of *relative equilibrium* in which their velocity is tolerably uniform. After this "terminal velocity" has been acquired, the TIME of passage of the Instrument across the space between two parallel cross-sections at a known distance apart, is carefully timed by one or more chronometers.

It must be observed that the actual Result obtained by this sort of observation is not the "velocity" at a particular point, either of the fluid or even of the "Float" itself,—using the term "velocity" in the sense of Art. 8,—but is really only the

"Average or mean of the 'velocities' of the 'Float' itself taken over the measured distance, which is expressed mathematically by $\left(\int_0^x v\,dx\right) \div x$", ...(2),

and it is assumed as nearly certain, that this is *the same as the average of the "velocities" of a fluid particle* over the same distance.

[For this reason, these "*Floats*" can only be used with any advantage in (so called) "uniform streams". In variable streams, a Fixed Instrument would be preferable when practicable].

The knowledge of this quantity, although not nearly so valuable as that of the "velocity"—both in direction and magnitude—of the fluid at a particular point would be for the important object of unravelling the laws of motion of fluid, is however almost as valuable for all practical purposes in calculating simply the "Discharge".

These Instruments can be used from a boat, and are therefore the most suitable for use in a very wide channel,—except *very close to the edges*, where a "Fixed Instrument" would be preferable, (*see* Art 35). They were almost exclusively used in the Mississippi Experiments, and have been also *exclusively used in these Experiments*.

With these Instruments, the following conditions should be fulfilled:—

1°. The whole Instrument in all its dimensions should be so small, as to disturb the natural motion of the water as little as possible.

2°. The dimensions of the parts of the Instrument should nowhere exceed a breadth and depth so small, that the "velocity" of the current is sensibly uniform throughout that breadth and depth.

[In the present experiments, these dimensions were fixed at a maximum of 3" × 3" for general use, but this *is too large near the edges*].

3°. The parts of the Instrument should be so arranged, as to severally expose a constant surface (both directly and laterally) to the current, *however the Instrument turns* during the motion,—(after the "terminal velocity" has been acquired)

4°. The Instrument should expose as little surface as possible to the wind.

5°. It should be strong enough and simple enough to bear moderately rough handling, and should be convenient to handle.

6. It should be cheap enough to admit of being made in large numbers.

The detailed description of Instruments (FLOATS) actually used, is deferred to Chapters. II., III., IV.

[In consequence of want of experience as to the best form of Instrument for velocity-measurement in a large Canal, the Author decided from the first to use *only the simplest and most inexpensive*, of such material as could be easily procured, and of such make up as could be readily executed in a small native bazar. This in part led to the sole use of "Free Instruments" (Floats) made of wood.

The experience now gained has pointed out the directions in which more expensive materials and better workmanship may be advantageously employed].

13. Objections to Floats.—As a spirited attack has been made by Mr. Révy (*see* Révy Report *passim*) on the use of FLOATS, utterly condemning their use at any rate on GREAT RIVERS, and especially for subsurface-velocity measurement, it seems essential to notice it here. Mr. Révy goes so far as to say of the Mississippi Survey—(*see* page 8 of Révy Report).

> "The Engineers of that Survey relied entirely on floats, and we consider it a misfortune to science and to practical Engineering that so much ability, perseverance, and time should have been spent to obtain results which the unfortunate choice of floats has inconveniently marred and confused".

This is a pretty decided condemnation of the use of FLOATS.

Mr. Révy admits, however, (p. 6,) that—"under favorable circumstances the velocity of the surface current may be observed by the movement of a float with considerable accuracy." Suffice it to say, as far as regards Experiments on a straight uniform Canal, the circumstances (which he points out as necessary to use of floats, *are favorable.*)

[*Mr. Révy, however, considers a down-stream wind of equal velocity with the Surface-current essential to accurate use of Floats. This is quite unnecessary in the Author's opinion: provided the floats do not project sensibly above the surface (compared with the mass buried below the surface)—a condition easily fulfilled on Canals and small rivers,—they will move sensibly along with the local surface-current, (which is itself of course affected by the wind). A calm or a simple up or down-stream wind would not affect the accuracy of the observations. A cross-wind would undoubtedly interfere seriously with the use of floats; but so it would with useful work with any form of Instrument*].

Mr. Révy's principal objections are however to the use of SUBSURFACE FLOATS.

Nevertheless the use of these Floats enabled the Mississippi Experimenters to clearly establish (page 225—262 of Mississippi Report).

1°. That the line of maximum velocity is *generally below* the surface.

2°. That its position depends on the wind.

[A law of dependence was even proposed].

Now both these Results are fully verified by the present Experiments conducted solely with FLOATS, and Result 1° is also fully borne out by the Darcy-Bazin Experiments, performed solely with a different Instrument (a Pitot's Tube).

It can be verified at once by any one for himself by simply throwing a chip of wood and a common beer-bottle filled with water enough to sink it pretty deeply into a current together, when the bottle will be found as a rule to move the quicker. It has also been long known to watermen that a deeply laden barge *floats more quickly down-stream* than a lightly laden one.

Result No. 1° (above) may be said to be one of the best established Results of modern Hydraulic Science.

The Instrument used by Mr. Révy,—a Current-metre—in preference to the Floats, which he condemns, *did not enable him to recognise this so easily established fact at all.* He declares, (p. 87,) relying on his Experiments with the Current-metre, that the maximum velocity line is at the Surface, and argues, (p. 87,) that it *ought to be so.* The inference would seem to be that this Instrument (Current-metre) is not so delicate an Instrument for velocity-measurement, as the (condemned) Floats.

The objections to the use of Sub-surface-Floats pointed out by Mr. Révy—*see* p. 5 to 8 of his work,—will be found fully detailed and discussed in Chap. III. of this Report, which *was written before the Author had seen Mr. Révy's work*].

Suffice it to say here, that the objections (though serious enough) are —in the author's opinion after this season's experience—by no means so insuperable (at any rate as applied to Canals not exceeding 9 feet in depth) as Mr. Révy considers. This will be understood better after reading Chap. III. These objections would be undoubtedly aggravated at greater depths.

But is the Current-metre proposed by Mr. Révy *more trustworthy* than the Sub-surface Floats? Comparative Experiments alone could decide this. Mr. Révy gives none.

14. Mode of observation.—It is convenient here to describe the

mode of observation adopted, which was the same in principle for all the FLOATS, the object being to

"Time as accurately as possible the passage of the Instrument across a known space.

This will be described under the following heads:—

LENGTH OF RUN,—Art. 15.	SOUNDING,—Art. 19.
ROPES and PENDANTS,—Art. 16.	WIND,—Art. 20.
BOATS and *Boat Rope*,—Art. 17.	CALCULATION,—Art. 21.
TIME-OBSERVING,—Art. 18.	

15. LENGTH OF RUN.—After many experiments with different "Lengths of Run"—(*i. e.*, spaces between the Upper and Lower Ropes)—varying from 200 feet downwards, the following were adopted as the Standard "Runs" for these Experiments,—

For about two-fifths of breadth of stream on either side of middle, ..	50 feet.
Outside above middle space, in general, ...	25 „
Close to banks, ...	12½ „

The length of "Run" should, *cæteris paribus* be as great as possible, for, the longer the "Run"—in a uniform stream—the less an error in observing the time affects the deduced "velocities", but it was soon found—in the course of the Experiments—that the "Floats" seldom run for any distance parallel to the axis of the stream, but gradually deviate from their intended line of motion, thereby passing into lines of (presumably) different velocity, and that *more and more with longer "Runs"*. After several trials it was found that 50 feet was the longest "Run" compatible with the accuracy aimed at—*i. e., compatible with the "Floats" running tolerably along the intended line*—and that this length must be gradually shortened on approaching the banks where the tendency to "deviation" is greater, and where—from the rapid change of velocity—any such deviation is of great importance.

[It may be observed that 50 feet was the Standard "Run" adopted* for the most critical of the Missipippi Experiments. It was considered desirable at the commencement of the present Experiments to adopt the same Standard "Run" (200 feet) as is ordered† for use by the Canal Engineers, but this was—after trial—abandoned for the reasons above].

16. ROPES and PENDANTS.—The length of "Run" was defined by two Ropes stretched right across from bank to bank, the distance between them being carefully laid out with a surveying chain. These will be termed for shortness the UPPER ROPE and LOWER ROPE.

* Report on Physics and Hydraulics of Mississippi, page 362.
† N. W. P., P. W. D. Irrigation Circular U of 1874.

Pieces of white cotton rope fastened to the Upper and Lower Ropes and suffered to hang freely down so as almost to graze the water were used to mark the spots where the Floats were intended to pass. These will be styled, for shortness, PENDANTS.

The spaces to be spanned by the "Ropes" were 82′ and 178′ respectively, (viz., 82′ at the Solání Aqueduct, and 178′ in the Solání Embankment). The stretching of a rope daily across these spans—in a stream running 3 miles an hour—*in such a manner as to satisfy all the conditions* of the Experiments, is not so easy a matter.

It is difficult to stretch the rope without wetting it: if stretched wet, the ropes yielded so much in drying as to shortly droop into the water: if alternately wet and dry, the stretching was so great as to destroy the correct spacing of the Pendants.

Surveying Chains would—if strong enough to bear the strain—be very convenient for this purpose, as the Pendants can be laid out along them without any trouble, and they stretch very little: but unfortunately they are not nearly strong enough, even for the 82′ span.

After repeated failures, the following plans were found successful and convenient.

For the 82 *feet span.*—Double grass ("múnjh") ropes were stretched across the span, and surveying chains were then underrun along them being slung from them by wire rings at every 10 feet. In this way the advantage of the use of chains was secured, and the chains—being supported at every 10′ were only slightly strained.

For the 178 *feet span.*—Some 1½-inch manilla rope was first strained for several days on shore, with a tension sufficient to reduce the Deflexion in the middle of a 200′ length (loaded with the intended number of Pendants) to 18″.

To prepare it for use, it was strained across the 178′ span at the spot where it was to be actually used, until its Deflexion at middle—as estimated by the eye, did not exceed 6″—and the two places where it crossed the parapet were *marked* with bits of white rope, which will be termed for shortness the "marks".

It was next strained *along the bank* close by, between two pegs spaced at 178′ apart, until the two "marks" were *brought up to the pegs.* The Pendants were then fastened on to it whilst lying along the bank by measurement from a 100-foot chain close by. It was then ready for use.

In stretching it for actual use, it was thereafter stretched across the 178′ span, and strained until the two marks were brought up to the parapet edges. It was considered that the spacing of the pendants was then very nearly correct.

The quality of the Manilla rope was such that—provided it were not wetted whilst stretching—its central Deflexion seldom increased during the course of a morning's work (about 4 to 5 hours) to an inconvenient amount. The lengths of Pendants were adjusted before starting, so as to admit of a moderate increase of Deflexion (in the Ropes)—about a foot at the middle—without their touching the water.

The amount of Deflexion conveniently admissible after once adjusting the lengths of the Pendants is obviously very small, as to admit of accurrate work the Pendants must always hang near to the water without touching it. So long as the "marks" are kept close up to the parapets, no moderate yielding of the 'Ropes' would sensibly effect the spacing of the "Pendants".

The spacing of the 'marks' and 'Pendants' was examined every few days.

[This method was found satisfactory, but it must be confessed to be troublesome: it would certainly be more convenient to use Surveying Chains supported by Ropes as was done for the 82′span. It is essential, however, that the Ropes used be so light as not to require blocks or tackle for stretching them on account of the trouble of daily erecting and taking them down].

17. Boats and Boat Rope.—Two Boats were in constant use, one above the Upper Rope for casting the "Floats" from, and one below the Lower Rope for catching the "Floats" after use. These Boats will be styled for shortness the *Upper Boat* and *Lower Boat*. Each Boat was kept in desired position by a pair of tow-ropes held by men on either bank.

The Upper Boat was placed at a distance above the Upper Rope, believed to be sufficient for the "Floats" to acquire their state of relative equilibrium (or terminal velocity) before reaching the Upper Rope. The following distances were adopted:—

For 'surface-floats' and 'sub-surface floats' not exceeding 3 feet in depth, ... 50 feet to 100 feet.
For 'sub-surface floats' exceeding 3′ in depth, ... 100 feet.

It is desirable to keep this distance as small as is compatible with the 'Floats' attaining their state of relative equilibrium, as every increase of this distance, increases the chance of the Floats' deviation to right or left of intended line of motion.

The above distances were usually defined by a Rope stretched from bank to bank: this will for shortness be termed the *Boat rope*.

The use of a boat for 'casting' the Floats from, is a necessary evil in a wide stream: the Boat actually used was a very light pleasure boat; its rudder was removed when in actual use, so as to remove one cause of disturbance of the water. Its stern was brought close up to the Boat rope, and was aligned with the two white 'Pendants' (on the Upper and Lower Ropes) defining the proposed line of motion of Floats.

The alignment was finally corrected by trial with a few 'surface-floats,' until a position was found from which the floats *entered the "Run" close to the proper 'Pendant.'*

In this way some allowance was made for wind.

[Should these Experiments be continued in future seasons, it would be worth while erecting a cheap temporary suspension bridge over the shorter span of 82′ feet for casting the "Floats" from, without their being affected by the wash of the boat].

The Lower Boat was kept about 20′ feet below the Lower Rope: its effective use—to enable the "Floats" to be caught again—requires that it should be pretty steady, and also admit of being rapidly shifted from side to side (by the two ropes) according to the ever-varying motion of the "Floats". In fact, the rapidity of work with all kinds of Sub-surface-Floats was found eventually to be *limited by the rapidity with which they could be removed from the water* by the men in this boat.

18. Time Observing.—Various methods of observing the time of passage of the Floats over their Run were tried. They may be classed according to the number of chronometers used.

[The 'personal equations' of the observers were found to affect the observations very markedly: in the Tables I. to XIII., herewith published, containing the details of the experiments, the "Time-keeper" is invariably distinguished by his initial].

i. *Two-chronometer Method.*—An observer sat opposite each rope, with a chronometer in front of him, and—whilst listening to the ticks of the chronometer—watched the passage of the float under his rope, and recorded the time *to the nearest half second.* The chronometers were timed both just before, and just after, each day's work, so that allowance might be made both for their *relative error* and for their *relative rate.*

An equal number of observations were made with the observers and chronometers interchanged from upper to lower rope; these observations were combined for the purpose of discussing the results so as to eliminate the effects of the observers' "relative personal equation".

This method is believed to afford the greatest accuracy possible without automatic registry. It also admits of comparatively great rapidity of field-work—when using surface floats,—an object of considerable importance under the hot Indian sun.

[It was found possible by this method to observe 'Floats' cast in the water at about 5-second intervals; great care is however required to ensure the rotation numbers of the floats being recognized by both observers. This rapidity can not be secured with any but Surface-floats, as Sub-surface floats could not be caught and lifted out of the water at this rate].

The labor of reduction of the observations of this method is however very great, as—being on different field-books—they must all be transferred or copied on to a single sheet, and every observed time-difference must be separately corrected for *both error and rate* of chronometers to give the true time-interval over the "Run." This in itself introduces considerable chance of error.

The effect of "personal equation" on single observations by this method is also considerable.

[The number of observations to be reduced in these Experiments was so large—often 200 a day *by a slower method*—that the labor of reduction was of serious importance. For this reason chiefly, this method was seldom used in these Experiments].

ii. *Single-chronometer Methods.*—After trial of several different methods, the following was finally adopted (after taking advice of one of the Staff of the Transit of Venus Expedition) as likely to yield the most trustworthy results:—

One observer sat with a chronometer in front of him midway between the two ropes: the second observer standing opposite the upper rope, warned the "time-keeper" of the approach of the float, and then *shouted* just as it passed under the upper rope; he then walked down to the lower rope, and standing opposite, shouted again just as the float passed under the lower rope. The time-keeper entered the number of chronometer-beats counted just as he caught each "shout" *to the nearest half-second.*

[After about middle of March, one of the Observers (Sergt. Warburton) observed to nearest quarter-second].

It will be observed that the "complete observation" at each Rope is *of same kind*, viz.,

(*a*). Watching the passage of a float, and giving an audible signal of its passage *by the same observer, at each rope.*

(*b*). Listening for an audible signal, and recording the time of its occurrence *by the same observer at each rope.*

This is considered to reduce the effect of "personal equations" of the observers to a minimum.

An equal number of observations were usually made with the observers ("shouter" and "time-keeper") interchanged; these observations were combined for the purpose of discussing the results so as to eliminate the remaining effects of the observers' "relative personal equation."

[One great merit of this mode of observation is the ease of reduction of the observations; as both observations are entered in the same field-book, it is unnecessary for the time-keeper to attend to, or record any figures but the beats (half-seconds) actually counted, which being entered in parallel columns, the difference is at once taken out *in the field*, thus yielding without any office work the Result only obtainable with the two-chronometer method by considerable labor in office. A Specimen of Field-book is here figured.

FIELD-BOOK.

PENDANT	Float No.	TIME		Time-interval	Mean Time-interval	Velocity	Deviation	Remarks (Wind, &c)
		Upper Rope	Lower Rope					

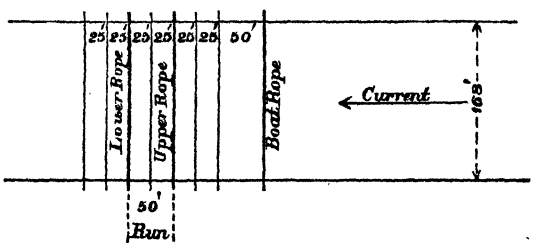
The rate of work with this method is limited by the time it takes a man to walk from the Upper Rope down to the Lower, and back again; so that it is much slower than the two-chronometer method when working with surface-floats: but this does not materially affect the rate of work with sub-surface floats, which is practically limited (Art. 16) by the difficulty of lifting them out of the water.

The general convenience of this method is however so great, that it was after a time almost exclusively used.]

19.—SOUNDINGS.—At each of the "Experimental Sections" (Art. 11), soundings were taken *on the line of every one of the Pendants* (Art. 16),

right across eight different transverse sections at 25′ *apart* above and below the "Experimental Section," as shown by sketch.

Fig. 5.



The mean of the depths on the line of each Pendant was considered the average depth along that line in the neighbourhood of the "Experimental Section".

[The bed in both Chambers of the Solání Aqueduct was found to be so level, that the soundings were not made over so many cross-sections].

With "Free Instruments" which register only the average of velocities (Art. 12—II.) taken right across the "Run," some such proceeding of estimating "the average depth for some distance along the line of each Pendant" seems essential.

[But even with "Fixed Instruments which purport to register the velocity *at a point*, it seems (to the Author) necessary to adopt a similar procedure, inasmuch as the velocity at a point is of course due to the configuration of the cross-sections both above and below the experimental cross-section, as well as to that of the latter.

In the Mississippi Experiments, it appears (page 223) that only two Cross-sections were taken at 200 feet apart.

In the French Experiments and Paraná Experiments, it does not appear that any cross-section, but the "experimental section" was measured].

The Sounding Rod used was a straight Rod fitted with a flat iron "shoe" $4''\frac{3}{8}$ diameter, to prevent it sinking into silt or into accidental interstices between bricks, boulders, &c., on the bed of the current.

20. WIND.—There appears to be no known way of eliminating or *estimating quantitatively* the effects of the Wind on the Experiments.

The Mississippi Experiments clearly show that a down-stream wind raises, and an up-stream wind depresses the axis of the parabola, which appears to be the vertical velocity curve; an empirical formula is given (Mississippi Report, p. 262) for the amount of this elevation and depression.

[The French Experimenters take no notice of the (previously published) above conclusion, and, indeed, assert (Darcy-Bazin Report, Chap. II.) that the Resistance of the Air has no sensible effect on the discharge.]

The present season's Experiments were not nearly extensive enough for this point to be tested.

The Direction and Velocity of the Wind were however estimated, and recorded *at beginning and end of each "Set"* of Experiments as follows:—

The DIRECTION was estimated in following conventional manner (very convenient for present purpose), viz., by the usual Compass points—(N., N. *b* E., N.N.E., &c.,)—the direction of the current being considered the WORKING MERIDIAN, (or N. S. line): the letter V was used to indicate "Direction Variable."

The VELOCITY was measured by using a small Wind-vane (by Negretti and Zambra) in conjunction with the Chronometer: the Wind-vane was compared with the Standard Anemometer of the Thomason College Observatory; each revolution of the Indicator was found to indicate the passage of 150 feet of Wind.

These Results will be found recorded in the Table of Abstracts of Experiments: the figures in the column of Velocity indicate *feet per second.*

No attempt has been made in this season's Experiments to allow for wind; thus all the Experiments—whether executed on a windy or on a calm day—have been considered as "of equal weight" in taking out averages.

[Should these Experiments be continued in other seasons, it may be worth while to assign less "weight" to the Experiments of a windy day].

21. CALCULATION.—The calculations performed in reducing the Results of Experiments have been very extensive.

Beginning from the preliminary reductions in the Field-Book itself, *every step has been checked by both the European observers.*

The preliminary reductions were—

1°. Subtraction of chronometer-beats counted at Upper Rope from those counted at Lower Rope: the difference is the "time-interval" over the Run.

2°. The *mean* of several (usually three) such time-intervals was next taken; this mean was considered the "time-interval" freed from mere observation-errors.

3°. The "velocity" corresponding was next found by dividing the Length of Standard Run by the above mean Time-interval (this was easily done by a Table of reciprocals; this was considered to be a *single Velocity-Measurement.*

The above was always done in the Field-book, (processes 1° and 2° usually in the Field) from day to day.

These VELOCITY-MEASUREMENTS were next transferred to sheets of Abstracts, (such as are published along with this Report), and arranged into SETS—constituting the ordinates of a Velocity-curve. Each Velocity-

curve was next plotted on a suitable scale, so as to exhibit its form to the eye, and its Area computed from the known ordinates. The Area-computation was of course very laborious work. This was done daily.

The SETS were next arranged into SERIES of Velocity-measurements at same place and with *nearly the same gauge-depth*. These are exhibited in the Tables herewith published. The means of the Velocity-measurements at each point in a SERIES was next taken: these were considered to be the MEAN VELOCITY-MEASUREMENETS at each point. From these were plotted Mean Velocity-curves, and their Areas computed.

An attempt was next made—with some success—to find the "Equation" which should nearly represent these MEAN CURVES: this of course involved much additional computation. Many other computations were undertaken whose object will appear in the Sequel.

The discussion of the above RESULTS constitutes the most important part of this Report.

[It may be here remarked that 'discordant observations', *i. e.*, observations apparently disagreeing with the average of the rest were never rejected unless the cause could be traced to mistake in some observation or want of adjustment of Instruments].

CHAPTER II.

SURFACE-VELOCITIES.

22. Surface Floats.—For measuring "surface velocities" in a wide channel not very close to the edges—there appears to be no more convenient Instrument than the ordinary "Surface-float". After several trials with floats of different sizes, the following were adopted as the pattern of "Surface-float".

Thin circular discs of English deal planed smooth and turned on a lathe.

(*a*). 3″ diameter, and ¼″ thick, *for general use.*

(*b*). 1″ diameter, and ⅛″ thick, for use close to the banks.

Some were painted white, some black, some were left uncolored to be used in different states of sunlight: on the whole nothing was found so convenient as a "marker" as a small pledget of white cotton-wool, loosely inserted in a small hole in the centre of the disc.

[For surface velocity measurements *quite close to the edge*, FLOATS were found unsuitable, *see* Art. 35: a Pitot's Tube would probably be the best Instrument in this position. Strictly speaking few Fixed Instruments will measure surface-velocities at all, as they require to be submerged sufficiently to properly cover their working parts, thus:—

1°. In the French Experiments, the nozzle of the Pitot's Tube was always submerged ·03 of a metre = 1·2 inches, nearly.

2°. In the Paraná Experiments, the Instrument was sunk from 6 to 12 inches.

23. Unsteady Motion.—The most perplexing phenomenon is that the Motion of Water is not even approximately STEADY. It may be well to give the following definition.

DEF. Motion is termed STEADY when the velocity at any point depends *only on the position of the point*, and is therefore constant both in direction and magnitude for each point.

It may be observed that in practical Treatises, all Results are based on the hypothesis that the Motion is STEADY, and that hardly any theoretical solution has been effected except for Steady Motion.

Any one watching the motion of water at the margin cannot fail to remark a continuous *slight variation* of level of very short period.

[In the Solání Aqueduct this variation is about ·05 of a foot, and runs through all its phases very rapidly].

This shows that the motion is slightly oscillatory, and therefore cannot be *perfectly steady.*

The oscillation is however—in a uniform channel of great length—so very slight and of such extremely short period, that there can be no doubt that the important equation—"Total Discharge through a complete cross-section = constant" is *sensibly true to a high degree of approximation* in a uniform channel of great length.

This is, however, by no means the case for the Discharge through very small parts of a cross-section, or in other words,

"The velocity at any particular point is not constant for that point but varies greatly from instant to instant," ..... } ...(3).

This Result may be seen in any of the Tables following, but is most conspicuously established by the following Experiment undertaken with the express view of testing this important point.

The Result is so important that it seems advisable to detail the Experiment very fully.

24. EXPERIMENT (SERIES 1).—The object of this Experiment was to time as accurately as possible the passage of a very rapid succession of floats over the same "Run," noting also the 'deviation' of each.

[This Experiment will be referred to as the first SERIES of observations].

To secure all possible accuracy on this occasion, the two-chronometer Method (Art. 18—i) was used, four European observers—denoted by the initials C., R., T., W.—acting in concert.

The "Run" chosen was along mid-channel of the Right Basin of the Solání Aqueduct; and the air was nearly uniformly calm.

EIGHT SETS of 15 surface-floats were dropped into the water in mid-channel by T. at nearly regular intervals,—the first set at about 10 second intervals, the remaining seven sets at about 5 second intervals—timed by a watch.

The times of passing the Upper and Lower Ropes were recorded *to nearest half second* by R. and W., using separate chronometers. During the first four SETS, W. sat at the Upper Rope, and R. at the Lower; the observers then changed places, *taking their chronometers with them.*

Pendants were hung from both Upper and Lower Ropes nearly grazing the water at mid-channel, and at points 5 feet and 10 feet both to right and left of the centre. The 'deviation' of each float from the centre at the Upper Rope was observed by C. from the Lower Boat—the 5 feet and 10 feet Pendants marking 5 feet and 10 feet spaces.

[With such rapid work, special precautions were necessary to admit of the rotation number of each float being recognized *by all three observers* (C., R., W.), as a single

mistake or omission on part of any one of them would have *risked the loss of all the observations*. To meet this difficulty, every third float was a black one, the rest being white, and the field books were ruled in sets of 3 lines separated by a black line, and the observers were instructed—in case of missing any 'float'—to wait for the next black one, the black ones being always entered as the leader of a set of three in the field-books. By this precaution most of the observations could be utilized].

The chronometers were compared both *just before* and just after the whole set of Experiments—which lasted altogether only about an hour—so as to ascertain both their relative error and relative rate. The Results of the comparison are here recorded to establish confidence in the accuracy of the work.

CHRONOMETER COMPARISONS.

	Chronometer.						Difference in ½ second	Mean Difference in ½ seconds	Rate.
	Frodsham			Dent					
	H	M	½S	H	M	½S			
1	8	47	28	8	46	112	36	Frodsham fast 35·6	Frodsham gaining 1·6 half seconds per hour.
2			38			123	35		
3			49			133	36		
4			57			142	35		
5			68			152	36		
1	9	46	91	9	46	54	37	Frodsham fast 37·2	
2			101			64	37		
3			109			72	37		
4			118			81	37		
5			126			88	38		

NAWAB SALAR JUNG BAHADUR

It will be observed that the discrepancy in the five comparisons (rapidly succeeding one another) in no case exceeds one beat, or a half-second.

[After *many* such comparisons between the observers, it was found that the discrepancy *in such observations* scarcely ever exceeded one beat or a half-second].

Now the actual observation of the floats—being a *visual* observation—is *susceptible of greater accuracy* than the chronometer-comparison—an *audible* observation.

It is inferred that *the probable error of individual observations does not exceed a half-second*, and that the great discrepancies in observed time of passage of the floats over the 50 feet Run—amounting as a maximum to seven half-seconds—are *due to real changes of velocity* of the water from instant to instant.

The differences of chronometer observations of corresponding floats *after correction*

for both relative error and relative rate of chronometers, are the true time-intervals of passage of floats over the 50′ "Run": from which the velocity in feet per second is immediately deduced.

[That there were *real changes of velocity* of the water was visible even to the eye, as the successive floats were constantly changing their relative distance: occasionally one float would nearly *catch up the preceding one.*

The Results are graphically exhibited in *Figs.* 6*a*, 6*a*, &c., 7*a*, 7*a*, &c. *Plate* II.

Abscissæ measured from A in each figure indicate the time at which each successive float passed the Upper Rope, reckoned in each case from the leading float marked A.

The ordinates in the upper figures (a, b, c, d) indicate the "velocities" of each successive float: the ordinates in the lower figures ($\alpha, \beta, \gamma, \delta$) indicate the "deviations" of the corresponding float to right or left of centre at the Upper Rope.

The figures show—by the unequal spacing of the ordinates—that though the floats were dropped at nearly regular intervals, and from nearly the same place, yet they reach the upper Rope at irregular intervals: they show also by their ordinates how irregular the "velocity" of successive floats was *both in magnitude and direction.*

The following Table is an Abstract of the maximum, mean, and minimum "velocity" in each of the sets of fifteen floats.

The figures (*Plate* II.) show the details sufficiently well.

	VELOCITIES								Abstract
	W. at Upper Rope				R. at Upper Rope				
Set	1	2	3	4	5	6	7	8	
Fig.	6*a*	6*b*	6*c*	6*d*	7*a*	7*b*	7*c*	7*d*	
Max.	4·07	4·20	4·35	4·13	3·91	4·10	3·82	4·00	Max. max^{m}. 4·35
Mean.	3·76	3·94	3·96	3·90	3·60	3·75	3·83	3·85	
Min.	3·50	3·73	3·57	3·55	3·27	3·52	3·31	3·57	Min. min^{m}. 3·27

An inspection of the figures (*Plate* II.) and Table will show that the observed values of the "velocity" varied from 3·27 to 4·35 feet per second, while the "deviation" from centre at the Upper Rope varied from 4′ left to 6′ right.

It must be observed that the Result of the first four Sets of floats are really *comparable only with each other;* and those of the second four Sets *with each other,* that is to say, the first four Sets are not fairly comparable with the second four Sets in consequence of the interchanged position of the observers.

It will be noticed that the means of the latter four Sets are almost all less than those of the first four Sets: this seems to be the effect of the 'personal equation' of the observers. It may be explained by supposing that in this sort of observation W. habitually observed a little too late, or R. a little too early.

The comparatively great discrepancy between the means of Sets of 15 floats

with the observers interchanged, shows how great the effect of 'personal equation' is on measurements of velocity, and how *extremely difficult it is to get absolute results*.

25. Conclusion that Motion is unsteady.—The above Experiment was undertaken with the hope of discovering the law of variation of the velocity of the central surface filament of the stream *with respect to the time*, but the Experiment shows that the total variation is of too short a period to admit of discovery of its law without observations *at very much shorter intervals* than five seconds. Increased rapidity of observation was, however, impracticable; for occasionally two floats would—even with this interval at starting—reach the Lower Rope separated by *only one-half second;* with shorter intervals successive floats would, therefore, probably have crossed one another, and thereby been *mistaken for one another*, which would of course falsify the results.

The general conclusion to be drawn from the Experiment is—

"The motion of water is *not even approximately* STEADY, *i. e.*, the velocity at a point *varies greatly* both in direction and magnitude from instant to instant,".....} ...(3).

This conclusion is *fully borne out by the whole course* of the Experiments*, although in other Experiments several floats in succession would often pass over their "Runs" in nearly the same time, still *discrepancies of one, two, or (occasionally) three half seconds were tolerably common*, and did not seem imputable to errors of observation. It may be seen in any of the Tables following, that the "velocities" along some line are very seldom quite alike.

This conclusion is noticed, but only somewhat cursorily, both in the Mississippi Experiments and French Experiments.

It seems, however, to the Author, of the very highest importance *as affecting the difficulty and probable expense* of Experiments sufficient to lead to useful results: for it shows conclusively that—

"Single Observations of velocity are—unless actually simultaneous, quite incomparable.".....} ...(4).

Now, the difficulties of observation preclude in general the possibility of any simultaneity of observations, so that single observations, would be of little use.

26. Average Steady Motion.—Further Experiment has led† to the conclusion that, *under similar external conditions*,—

* *e. g., see* Art. **29, 57.**

† *See* Art. **31, 60.**

"The AVERAGE 'VELOCITY' at a point, taken through a considerable interval of time, is constant in magnitude", ... } ...(5).

Which may be mathematically expressed thus :—

"The instantaneous velocity (u) is variable, but the mean velocity $\left(\int_0^t u dt\right) \div t$ = constant when t is very great, so that there is, .. } .(5a).

AVERAGE STEADY MOTION."

The 'external conditions' (*e. g.*, wind, and depth of water) under which each separate velocity-measurement is effected, are liable to considerable variation—especially the state of the wind. Hence follows the further important conclusion—

"To secure comparable Results from Experiment, freed from the effects of variation of external conditions, it is necessary that the number of measurements of velocity at any one point be very great," ..... } ...(6).

Which involves as a necessary consequence—

"Hydraulic Experiments to be useful must be necessarily very tedious and therefore very expensive, ... } ...(7

27. Surface-Velocity variation.—Many experiments were mad to determine the Surface Velocity-curve. The Results are arranged i SERIES, Nos. 2 to 8, Tables I. to III. It was soon found that the Surfa Velocity-variation is very slight for $\frac{3}{4}$ of width of channel about mi channel, and very great near the banks. Velocities were according measured at considerable intervals near mid-channel, the intervals beir gradually diminished towards the banks.

The intervals chosen were as follows *reckoned outwards from mi channel.*

SOLANI AQUEDUCT.

Left Chamber.—42′½ half width.

Left of Centre.	Centre.	Right of Centre.
39′½, 37′½, 35′, 32′½, 30′, 20′, 10′,		10′, 20′, 30′, 32′½, 35′, 37′½, 40′, 41′½, 4

Right Chamber.—42′½ half width.

Left of Centre.	Centre.	Right of Centre.
41′·8, 41′½, 40′, 37′½, 35′, 32′½, 30′, 20′, 10′,		10′, 20′, 30′, 32′½, 33′, 37′½, 3

SOLANI EMBANKMENT.

Surface half-width about 84′ 4″ but varying with depth.

Left of Centre.	Centre.	Right of Centre.
82′, 80′, 75′, 70′, 65′, 60′, 40′, 20′,		20′, 40′, 60′, 65′, 70′, 75′, 80′, 82′.

Thus the Surface-Velocity was actually measured—

(1) at 17 places in breadth of *each* chamber of Solání Aqueduct.

(2) at 17 places in breadth of Solání Embankment.

[It will be remarked that in the Chambers of the Solání Aqueduct the measurements are not so close to the edge at the outer margins (*i. e.*, left bank of Left Chamber and right bank of Right Chamber) as at the inner margins along the central Pier—(*see* Description of the Aqueduct, Art. 10—iii). This is caused by the corbelling out of the tow foot paths, about 3′ over the water's edge, which prevents observations close to the outer margins.]

28. *Order of Observation.*—After general preliminary trials, the following arrangements were finally adopted:—

A maximum 'deviation'—of about 2′ at mid-channel, and decreasing gradually to 2″ or 3″ near the edges—from the proper Pendant at the Upper Rope was considered inadmissible. Floats not passing within these intervals *were not recorded.*

At any one line, Floats were passed until a set of three (all passing within the admissible 'deviation') had been recorded; the boat was then shifted to the next position, where a similar set of three velocity-measurements were made, and so on.

This process was begun at one bank and carried gradually right across to the other: the Result will be called a "SET" of velocity-measurements.

The observers then changed places, and the whole of the above process was repeated in the opposite order, constituting a second SET.

A third SET would then be executed with observers again interchanged, and so on. Under favorable circumstances, one SET of velocity-measurements was executed in an hour.

The above arrangements were adopted for following reasons,—

a. Three observations at each line were considered necessary to eliminate mere errors of observation.

b. The interchange of observers to eliminate 'personal equation.'

c. The number was limited to three to allow of measurements right across the channel within a moderately short time, and therefore under somewhat similar external conditions.

29. *Reduction of the Observations.*—The mean of each set of three velocity-measurements along any one line was considered to be the "velocity" along that line *freed from observation errors.*

These 'velocities' so found were plotted—for each SET—on a suitable scale perpendicular to a base line representing the surface width of the channel, thus laying down 17 points in the Surface Velocity-Curve (Art. 9) which was completed free hand. Each day's work was plotted on the same base line; so that two to four Surface Velocity-Curves were plotted on the same base line.

The particular Curves were found to be *of very irregular shape*, and to *disagree extremely in detail*, the position of the line of maximum surface velocity varying over half the width of the stream: in fact the disagreement between each curve was so great as to render it at first sight seemingly a hopeless task to disentangle any simple laws out of such variable data.

[This great variability will be recognised as the necessary consequence of the fluid motion being really UNSTEADY, as explained in Art. 25].

It seems unnecessary to publish all the daily curves: a few only (*Plate* III.) are annexed, to exhibit their disagreement.

30. Surface-Discharge.—After a time, however, it seemed probable that the curves—though disagreeing greatly in detail—interlaced in such a manner as to be *of tolerably constant area.* To test this point, the area of each separate curve was calculated as accurately* as possible.

It will be seen that the measured ordinates of the Curves divide them naturally into 5 sections, which are sub-divided into 2, 3, 4, or 6 equal spaces by measured ordinates—(the ordinates being of course velocities). The Area of each Section was separately calculated: that of the central (a 6-space section) by Weddle's* Rule: that of the rest by Simpson's *Rule (for a 2-space, a 4-space section) or by the cubic* Rule (for a 3-space Section).

In computing these Areas, the extreme ordinates (marginal surface-velocities) which do not admit of direct measurement have been *assumed* to be zero: the validity of this assumption is discussed in Art. 35; their magnitude is certainly very small, and the width of surface affected by it (in computation of area) is a very small fraction of the whole Surface width, so that the resulting value of the Area is *not sensibly affected by an error in estimating the marginal velocity.*

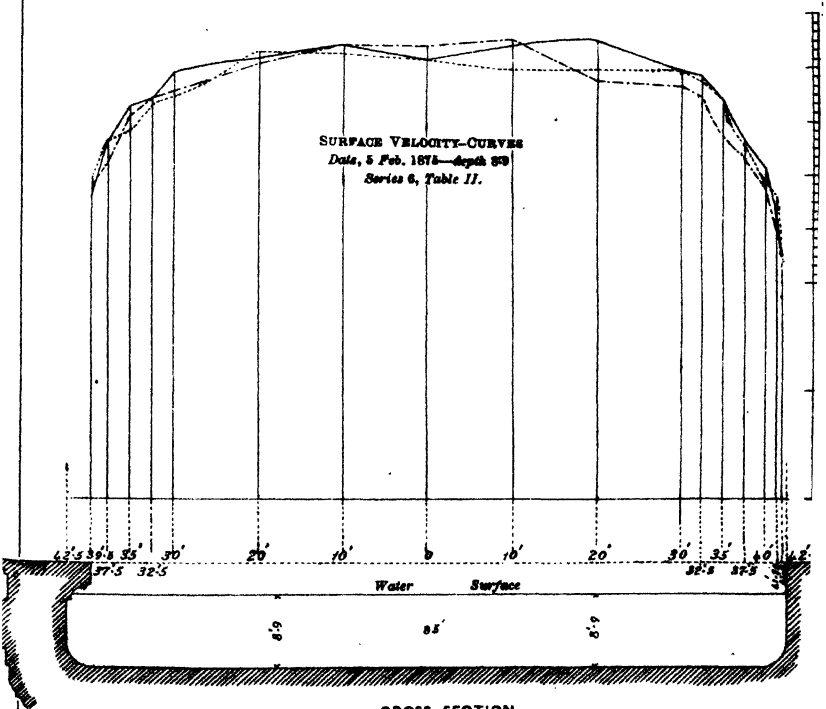
* *See* Moore's Elementary Mensuration for a complete exposition of formulæ for approximate calculation of areas.

HYDRAULIC EXPERIMENTS AT ROORKEE.

SURFACE VELOCITY-CURVES

at Centre-section of Solání Aqueduct, Left Chamber.

Abscissæ indicate distances from the centre of the Cross-section.
Ordinates indicate surface velocities.
Scale for Cross-section and abscissæ, 20 feet to an inch.
Scale for ordinates (velocities), 15 feet per second to an inch.



CROSS SECTION.

A Cunningha

The Results are exhibited in Tables I.—III., of which the following is an Abstract of contents:—

Table	Serial No.	Number of "Sets" of Observations in each "Series"	Number of points of velocity measurement	Gauge-depth	Approximate Surface-Width	Locality	Position of Experimental Section	Remarks
I.	2	6	7	9'·30—9'·70	168'8"	Solání Embankment.	2860 ft. above Solání Aqueduct.	[N.B.—Every "Velocity-measurement" is the mean of at least three observations.
	3	5	17	8'·95	168'		Ditto.	
		5	17	8'·85—9'·00	168'		3195 ft. above Solání Aqueduct.	
II.	4	8	7	9'·45—9'·6	84'	Solání Aqueduct	Centre of Left Chamber.	
	5	15	14	8'·90—9'·05	84'3"			
	6	14	17	8'·75—8'·90	84'3"			
III.	7	16	17	8'·65—8'·80	84'6"	Solání Aqueduct	Centre of Right Chamber.	
	8	3	17	9'·15	84'3"			

The SETS are arranged into SERIES for intercomparison *according to the variation of Gauge-depth*—it being considered that Experiments are comparable only under similar circumstances—a principal condition of which is *approximate equality of gauge-depth.*

Col. 3 of the Tables (I., II., III.) exhibits the details of velocity-measurement along each 'line of motion'. Each horizontal line exhibits a complete SET of ordinates of *one* 'velocity-curve'. Col. 4 exhibits the areas of the individual 'velocity-curves'—which of course represent the SURFACE-DISCHARGE at the Section (in square feet per second).

It will be seen that much as the Details of each separate Curve (compare the figures in *any one* vertical column under Col. 3) differ, the Areas (Col. 4) are *tolerably constant*, and that the discrepancies in these are chiefly due to the Observers' 'personal equations'.

The 'Timekeeper' of each SET is indicated by his initial (W. or R.) in Col. 6; after combining the Results (of Col. 5) by pairs (W., R.), so as to eliminate as much as possible the effects of 'personal equation,' the Results, *see* Col. 7—are *much more approximately constant*, the discrepancies from the mean of Col. 4 being shown in Col. 8.

TABLE

SURFACE-VELOCITIES

SOLANI EMBANKMENT—*Surface*

Serial No.	1 Date 1874-75.	2 Gauge-depth.		3 SURFACE VELOCITIES [Each Velocity is the mean											
				Left of centre.									Centre.	20	40
				84	82	80	75	70	65	60	40	20			
SERIES 2.	16·12	9·30		Details omitted for											
		9·30													
	22·12	9·50		The Ropes used on these days stretched so much, that the actual											
		9·50		effected at the proper distances from the centre.											
	24·12	9·70		The calculated Surface-Discharges have been											
	29·12	9·60													
SERIES 3.	7·1	8·95	Assumed zero,—*see* Art. **35.**	..	2·46	3·41	3·80	3·95	4·29	4·48	4·05	4·05	4·35	4·35
	8·1	8·95		2·50	3·41	3·61	3·70	3·95	4·17	4·35	4·22	4·11	4·35	4·69
		„		2·11	3·12	3·57	3·52	3·94	4·00	4·41	4·34	4·16	3·79	4·22
	9·1	8·95		2·13	3·09	3·45	3·66	4·00	4·11	4·29	4·41	4·55	4·41	4·55
		„		2·33	2·97	3·57	3·85	4·05	4·05	4·17	4·17	4·35	4·05	4·29
	13·1	9·00		2·22	3·19	3·45	3·75	4·05	4·35	4·55	4·35	4·35	4·41	4·17
	14·1	9·00		2·27	3·26	3·57	3·85	4·11	4·55	4·61	4·05	4·55	4·29	4·41
		8·97		2·50	3·53	3·90	3·90	4·41	4·35	4·17	4·29	4·22	4·11	4·22
	15·1	8·85		2·17	3·13	3·45	3·75	4·00	4·17	4·76	4·55	4·17	4·61	4·48
		8·85		1·89	2·78	3·23	3·70	3·80	3·90	4·55	4·29	3·90	4·17	4·17
	a Observed Means		0	2·52	3·09	3·52	3·75	4·03	4·19	4·43	4·27	4·24	4·25	4·36

I.

AND DISCHARGES.

Width, about 168 *feet.*

LOCITIES. of three observations]. Right of centre. 60	65	70	75	80	82	84		4 SURFACE-DISCHARGE in sqr. ft. per sec.	5 WIND. From	To	6 Timekeeper's Initial.	7 SURFACE-DISCHARGE. (personal equation eliminated).	8 Difference from Mean Value.
these four days.								702·62	Not observed.	Not observed.	W	697·58	These observations are incompatible in consequence of the great variation of gauge-depth.
velocity measurements could not be								692·55			R		
								684·28			R	686·55	
corrected for stretching of rope.								688·83			W		
								704·00			C	715·40	
								726·80			W		
4·29	4·41	3·80	3·85	3·23	..			681·07	N E	S E	R		
4·22	3·90	3·80	3·66	3·37	2·59			671·40	. 0	0	W	680·75	— 4·07
4·11	3·94	3·67	3·57	3·33	2·70			690·10	E	E	R		
4·29	4·17	3·85	3·75	3·19	2·56			674·56	E 17	N E 3	R	687·77	+ 2·95
4·22	3·95	3·66	3·53	2·86	2·22			700·98	E 27	E 14	W		
4·05	3·90	3·61	3·33	3·06	2·34			684·64	S W 12	S E 10	W		
4·22	4·05	3·85	3·53	3·26	2·22			707·93	S W 11	S W 2	W	693·11	+ 8·29
4·17	4·00	3·80	3·53	2·88	2·27			678·28	S W 11	W 27	R		
4·22	4·17	4·05	3·85	3·03	2·22			699·82	N 11	E b N 7	W	679·62	— 5·20
4·29	4·00	3·70	3·53	2·91	2·16			659·42	N E 11	S E 4	R		
4·21	4·05	3·78	3·61	3·11	2·66	0		684·82	..	..	..	..	..

Assumed zero,—*see* Art. **35.**

TABLE

SURFACE-VELOCITIES

SOLANI AQUEDUCT, LEFT CHAM-

Serial No.	1	2	3										
	Date 1874-75.	Gauge-depth.	SURFACE-VE- (Each Velocity is the mean										
			Left of centre.							Centre.	Right of		
			42½	39½	37½	35	32½	30	20	10	10	20	30
SERIES 4.	17·12	9·45	Details omitted for										
	18·12	9·6											
	19·12	9·5	The Ropes used on these days stretched so much, that the actual										
	21·12	9·5	effected at the proper distances from the centre.										
	a Observed Means.		The calculated Discharges have been										
SERIES 5.	21·1	9·05	Assumed zero,—*see* Art. 35.	..	3·30	3·53	..	3·80	4·29	4·17	4·35	4·22	4·29	3·95
		„		..	3·30	3·57	..	3·90	4·17	4·55	4·35	4·35	3·90	3·85
		„		..	3·13	3·33	..	3·85	4·11	4·29	4·29	4·11	4·00	4·00
	22·1	9·00		..	3·33	3·75	..	4·22	4·35	4·29	4·22	4·29	4·35	4·17
		„		..	3·19	3·49	..	4·05	4·17	4·41	4·17	4·22	4·29	4·00
		„		..	3·49	3·75	..	4·11	4·29	4·29	4·11	4·17	4·17	4·00
	23·1	8·90		..	2·94	3·26	..	3·95	4·22	4·29	4·35	4·55	4·35	4·05
		„		..	3·26	3·66	..	4·00	4·17	4·48	4·29	4·29	4·17	4·11
		„		..	3·06	3·66	..	3·95	4·11	4·11	4·35	4·29	4·22	3·80
		„		..	3·33	3·57	..	3·95	4·22	4·41	4·17	4·29	4·11	4·11
		„		..	2·94	3·66	..	3·70	3·85	4·11	4·17	4·05	4·05	3·80
	25·1	8·95		2·78	3·13	3·57	..	3·90	3·95	4·35	4·29	4·17	3·90	3·95
		„		2·83	3·13	3·41	..	3·80	4·17	4·35	4·22	4·35	4·11	3·85
		„		2·78	3·19	3·41	..	3·75	4·22	4·29	4·17	4·22	4·05	4·29
		„		2·83	3·33	3·67	..	3·75	4·00	4·22	4·17	4·06	4·11	3·90
	a Observed Means,		0	2·80	3·20	3·55	..	3·91	4·15	4·31	4·24	4·24	4·14	3·99
	b By formulæ, ..		*0*	*3·02*	*3·36*	*3·64*	..	*3·96*	*4·20*	*4·25*	*4·25*	*4·25*	*4·20*	*3·96*
	c Discrepancy, ..		0	− ·22	− ·16	− ·09	..	− ·05	− ·05	+ ·06	− ·01	− ·01	− ·06	+ ·03
SERIES 6.	1·2	8·80	Assumed zero,—*see* Art. 35.	3·06	3·19	3·40	3·75	3·90	4·17	4·29	4·11	4·35	4·11	4·00
		„		2·88	3·19	3·33	3·61	3·70	4·05	3·90	4·11	4·05	4·05	3·85
		„		3·00	3·33	3·57	3·90	4·00	4·05	4·29	4·35	4·22	4·05	4·00
	2·2	8·80		2·83	3·19	3·66	4·05	4·05	4·11	4·17	4·41	4·29	4·22	4·11
		„		2·78	3·13	3·57	3·70	3·85	4·22	4·29	4·41	4·35	4·17	4·11
		„		2·88	3·33	3·33	3·61	3·80	4·22	4·29	4·29	4·11	4·11	4·05
	4·2	8·80		2·78	3·33	3·40	3·75	3·90	4·29	4·41	4·48	4·22	4·17	4·11
		„		2·94	3·19	3·40	3·61	4·11	4·22	4·11	4·17	4·48	4·22	4·05
		„		2·94	3·19	3·49	3·80	3·95	4·22	4·55	4·41	4·29	4·11	3·95
	6·2	8·75		2·78	3·19	3·40	3·75	3·85	4·05	4·11	4·00	4·17	4·00	3·85
	5·2	8·90		2·78	3·19	3·57	3·66	3·90	4·05	4·17	4·05	4·17	4·22	3·95
		„		2·94	3·26	3·33	3·61	3·66	4·11	4·11	4·05	3·95	3·95	3·95
		„		2·88	3·06	3·49	3·66	3·70	4·00	4·17	4·17	4·22	3·85	3·80
		„		2·83	3·26	3·49	3·49	3·75	4·11	4·35	4·17	4·05	3·95	3·85
	a Observed Means		0	2·89	3·22	3·46	3·71	3·87	4·14	4·32	4·24	4·21	4·09	3·98
	b By formulæ ..		*0*	*3·02*	*3·36*	*3·64*	*3·83*	*3·96*	*4·20*	*4·25*	*4·25*	*4·25*	*4·20*	*3·96*
	c Discrepancy, ..		0	− ·13	− ·14	− ·18	− ·12	− ·09	− ·06	+ ·07	− ·01	− ·04	− ·11	+ ·02

II.

AND DISCHARGES.

BER—*Surface Width, 84 to 85 feet.*

LOCITIES. of three observations]. centre.							4	5		6	7	8
							SURFACE-DISCHARGE in sqr. ft. per sec.	WIND. From	WIND. To	Timekeeper's Initial.	SURFACE-DISCHARGE. (personal equation eliminated)	Difference from Mean Value.
32½	35	37½	40	41½	41·9	42½						
							342·26			W		
							337·77			R	340·02	+ 1·81
							341·80			W		
							342·54			R	342·17	+ 3·96
							339·53			C		
							334·08			C	336·81	— 1·40
							333·26			W		
							334·41			R	333·84	— 4·37
these four days. velocity measurements could not be corrected for stretching of ropes.							338·21	Not observed.	Not observed.			
..	3·75	3·26	2·97	..	..		334·00	S S W 9	S W 9	W	331·05	+ 1·94
..	3·66	3·26	2·86	..	..		328·10	S S W 9	S W 9	R		
..	3·61	3·45	2·80	..	..		324·58	S W 9	S W 9	W	..	
..	3·85	3·57	3·00	..	..		339·95	0	0	W	335·21	+ 6·10
..	3·66	3·33	2·94	..	..		330·46	0	0	R		
..	3·85	3·41	2·73	..	..		332·64	0	0	R	333·37	+ 4·26
..	3·66	3·49	2·88	..	..		334·09	0	S W 5	W		
..	3·75	3·41	3·06	..	..		333·49	0	0	W	325·64	— 3·47
..	3·75	3·41	2·83	..	..		317·78	S 11	0	R		
..	3·75	3·41	3·00	..	..		330 47	0	0	W	330·18	+ 1·07
..	3·66	3·41	3·00	..	..		329·89	S 11	S ŏW 11	R		
..	3·33	3 06	3·06	2·34	..		322·64	S ?	S ?	R	324·83	— 4·28
..	3·49	3·19	2·94	2·38	..		327·11	S W ?	S W ?	W		
..	3·33	3·41	2·78	2·28	..		327·55	S W ?	S W ?	R	325·73	+ 3·38
..	3·41	3·19	3·00	2·68	..		323·91	S W ?	W ?	W		
Assumed zero,—*see* Art. **35**.												
..	3·63	3·35	2·92	2·42	..	0	329·11					
..	*3·64*	*3·36*	*2·89*	*2·46*	..	*0*	*334·88*	*See* Art. **33**, Formulæ (11), (12).				
..	— ·01	— ·01	+ ·03	— ·04	..	0	— 5·77					
3·85	3·75	3·40	3·13	2·78	2·50		326·74	0	0	W		
3·95	3·33	3·19	2·83	2·94	1 88		319·32	S W 15	S W 15	R	323·03	— 3·63
3·90	3·66	3·33	2·94	2·78	2·34		329·06	0	S W 15	W		
4 00	4·17	3·57	3·33	2·94	2·08		336·72	0	0	R	332·89	+ 6·23
4·00	3 85	3·40	3·13	2·88	2·14		334·34	0	0	W		
4·05	3·66	3·49	3·26	2·94	2·21		330·67	0	S E 5	R	332·51	+ 5·85
4·00	3·85	3·57	3·13	2·68	2·34		338 01	N 11	N E 10	W		
3·70	3·75	3·49	3·40	3·06	2·34		331·02	N 10	N E 9	R	334·52	+ 7·86
3·85	3 57	3·40	3·00	2·73	2·21		333·08	N E 9	S E 10	W		
3·80	3·40	3 00	3·13	2·50	2·14		316·48	0	S W 15	R	324·78	— 1·88
3·90	3·66	3·33	3·06	2·72	2·20		323·57	W 6	S 8	R		
3·85	3·66	3·26	2·94	2·78	2·27		318·12	S 8	S 15	W	320·85	— 5·81
3·70	3·33	3·13	2·88	2·50	2·14		315·36	S 15	S W 10	R		
3·90	3·49	3·33	2·83	2·68	2·27		320·78	0	S W 15	W	318·07	— 8·59
Assumed zero,—*see* Art. **35**.												
3·90	3·67	3·38	3·07	2·80	2·22	0	326·66					
3·83	*3 64*	*3·36*	*2 89*	*2 46*	*2·18*	*0*	*334·83*	*See* Art. **33**, Formulæ (11), (12).				
+ ·07	+ ·03	+ ·02	+ ·18	+ ·34	+ ·04	0	— 8·2$_2$					

TABLE

SURFACE-VELOCITIES

Solani Aqueduct, Right Cham-

Serial No.	1 Date 1875.	2 Gauge-depth.	3 Surface Ve- [Each velocity is the mean										
			Left of centre.									Centre.	10
			42½	41·8	41½	40	37½	35	32½	30	20	10	
Series 7.	8·2	8·75	Assumed zero,—*see* Art. **35.**	2·27	2·78	2·83	3·19	3·57	4·11	4·11	4·22	4·11	4·22	4·35
		„		1·78	2·59	2·78	3·26	3·75	3·95	4·05	4·17	4·17	4·69	4·41
		„		2·34	2·46	2·83	3·26	3·49	4·00	4·05	4·17	4·11	4·48	4·22
	9·2	8·75		1·97	2·72	3·13	3·26	3·75	4·11	4·22	4·00	4·17	4·17	4·29
		„		1·92	2·59	2·94	3·33	3·75	3·95	4·11	4·29	4·11	4·41	4·17
		„		1·92	2·88	3·00	3·40	3·66	4·00	3·90	4·17	4·11	4·11	4·17
		„		2·03	2·54	2·94	3·33	3·57	3·90	3·90	4·22	4·41	4·17	4·00
	11·2	8·80		2·08	2·46	2·94	3·19	3·75	3·90	4·00	4·05	4·22	4·29	4·11
		„		2·14	2·46	2·88	3·26	3·40	3·80	3·95	4·00	4·05	4·22	4·29
	12·2	8·65		2·08	2·54	2·88	3·33	3·49	3·70	3·90	3·90	4·00	3·90	4·22
		„		2·03	2·59	3·19	3·33	3·57	3·70	3·75	3·85	3·66	4·05	4·00
		„		2·34	2·54	2·94	3·26	3·66	3·57	3·85	3·70	3·80	4·17	4·00
	13·2	8·65		1·92	2·67	2·83	3·13	3·49	4·05	4·05	4·22	4·17	4·00	4·00
		„		2·03	2·50	2·94	3·40	3·49	3·61	4·05	3·90	3·90	3·95	4·00
		„		2·03	2·38	2·94	3·26	3·57	3·95	3·95	3·90	4·11	4·29	4·22
		„		2·03	2·73	2·88	3·40	3·49	3·85	3·95	3·80	3·95	3·95	4·00
	a Observed Means		0	2·06	2·58	2·93	3·29	3·59	3·89	3·99	4·04	4·08	4·19	4·11
	b By formulæ, ..		*0*	*2·15*	*2·43*	*2·85*	*3·32*	*3·59*	*3·78*	*3·90*	*4·14*	*4·19*	*4·19*	*4·11*
	c Discrepancy, ..		..	−·09	+·5	+·08	−·03	..	+·11	+·09	−·10	−·11	..	−·0
Series 8.	10·2	9·15	Assumed zero,	2·20	2·72	3·13	3·49	3·85	4·00	4·29	4·29	4·22	4·22	4·4
		„		1·92	2·63	2·88	3·33	3·75	3·85	4·11	4·22	4·29	4·35	4·1
		„		2·14	2·63	3·00	3·19	3·41	3·95	4·05	4·22	4·00	4·22	4·2
	a Observed Means			2·09	2·66	3·00	3·34	3·67	3·93	4·15	4·24	4·17	4·26	4·2

III.

AND DISCHARGES.

BER—*Surface Width, 84 to 85 feet.*

LOCITIES. of three observations] Right of centre. 20	30	32½	35	37½	39½	42½	4 SURFACE-DISCHARGE in sqr. ft. per sec.	5 WIND. From	To	6 Timekeeper's Initial.	7 SURFACE-DISCHARGE. (personal equation eliminated).	8 Difference from Mean Value.
4·29	3·90	3·57	3·13	3·06	2·78		329·63	0	0	W	334·68	+12·96
4·35	4·05	3·80	3·19	3·19	2·78		339·72	0	0	R		
4·00	3·75	3·61	3·40	3·19	3·78		328·23	0	0	W		
4·29	3·95	3·80	3·33	3·26	2·63		328·40	0	0	R	330·40	+8·68
4·11	3·85	3·80	3·66	3·19	2·63		332·39	0	0	W		
4·29	3·80	3·70	3·49	3·06	2·83		327·15	0	0	R	327·45	+5·73
4·22	3·90	3·66	3·49	3·33	2·59		327·75	0	S W 5	W		
4·17	3·90	3·70	3·49	3·06	2·88		326·13	0	0	W	321·81	+0·09
3·90	3·85	3·40	3·49	3·13	2·42		317·49	S 10	0	R		
4·00	3·80	3·57	3·49	3·33	2·88		313·09	0	0	W	310·62	−11·10
3·95	3·61	3·45	3·49	2·88	2·73		308·15	S W 8	0	R		
3·80	3·57	3·37	3·13	2·88	2·59		306·26	S 23	S W 8	W		
4·00	3·61	3·57	3·33	3·13	2·88		319·26	0	0	R	314·55	−7·17
4·11	3·66	3·61	3·57	3·26	2·88		309·93	0	0	W		
4·11	3·61	3·53	3·49	3·26	2·94		321·82	0	0	R	316·94	−4·78
3·95	3·85	3·70	3·49	3·06	2·88		312·05	0	0	W		
4·09	3·79	3·62	3·42	3·14	2·76	0	321·72					
4·14	*3·90*	*3·78*	*3·59*	*3·32*	*2·97*	*0*	*330·15*	*See* Art. **33**, Formulæ (11), (12).				
−·05	−·11	−·16	−·17	−·18	−·09	0	−8·43					
4·05	3·66	3·61	3·40	3·40	2·42		330·13	N 14	0	R		
4·11	3·80	3·75	3·49	3·26	2·63		330·24	0	0	W		
4·29	3·85	3·66	3·41	3·26	2·63		329·07	W 19	0	R		
4·15	3·77	3·67	3·43	3·31	2·56		329·81					

Assumed zero,—*see* Art. **35**.

These discrepancies are—*considering the variable state of the external conditions*—(principally wind) all comparatively small quantities, the *largest* (at top of Table III.) being 12·96 out of 321·72, or about $\frac{1}{25}$th part of the quantity measured, and the majority far less.

This can only be due to one of two causes—either,

1°. The Total Surface Discharge is approximately constant under similar external conditions, though its distribution across the surface is very variable from instant to instant, ... (8).

2°. Or else, the velocity-measurements in each 'stream-line' not being simultaneous, (but taken in succession,) it is probable that each velocity-measurement is affected *at a different phase in the variation* of the velocity in that stream-line: in which case it is possible that the Total Discharge as computed from a number (17) of velocity-measurements *in different phases of their variation* may be *nearly the same* (on the whole) *as if each velocity-measurement had been a measurement at its own mean phase*, ... (9).

The former Result would—if it could be established—be one of great interest, as it is certainly not yet known to be a law of fluid motion. Unfortunately the second explanation equally well explains the close approximation of the numerical values of the Surface Discharges, and without the means of making really *simultaneous observations*, it would be impossible to detect which explanation was the true one.

[Similar Results will be proved Art. 58, for the (superficial) Discharge in a vertical plane. It would be important to extend these Experiments to other horizontal planes besides the Surface, but this could not be done in one season].

31. Surface Velocity Mean Curve.—It has been explained that the particular Velocity Curves of each "Set" of velocity-measurement were of very irregular shape, and disagreeing in detail. When however many "Sets" of measurements had been made, and the mean of velocity-measurements calculated for each line of motion, the Mean Curve resulting from plotting these "mean velocities" was found to be a strikingly *regular curve* lying nearly symmetrically about mid-channel.

See Plates IV., V., which exhibits the four surface-velocity Mean Curves resulting from the Series Nos. 3, 5, 6, 7 of 10, 15, 14, 16 "Sets," respectively, of which the details are given in Tables I., II., III.,

This points to the conclusion (Result (5) of Art. 26) that

"The mean 'velocity' at a point—taken through a considerable interval of time—is contant in magnitude under the same external conditions."

This conclusion being once adopted, it follows that the MEAN CURVE of Surface Velocity is *invariable in form* under the same external condi-

tions at the same section, and that, therefore, this Average surface-velocity at any point is a function *solely of the position* of the point in the surface, so that—

If u = average surface-velocity at a distance y from mid-channel,

$$u = f(y), \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10).$$

The form of the function (f) must be expected, however, to depend on the shape of the cross-section, on the nature of the bed and banks, on the slope of the bed, as well as on the external conditions.

[The difference of form of the Mean Curves in *Plates* IV., V.; the statement in the Mississippi Report, (p. 237,) that this Curve is a parabola (in certain cases); the difference of form of the Surface Velocity Curves in the Darcy-Bazin Report; and the statement in the Révy Report, *v. infra*, that the Surface-velocity at points in the section varies as the depths under those points (in certain cases): all these considered together, make it certain that the functional form (f) depends on these varying elements].

32. *Remarks on the Révy Results.*—Mr. Révy asserts (page 114—119, and 143 and 147 of Révy Report), that

"The Surface-Velocity at any point of the same cross-section is simply *proportional to the depth* at that point", ... }

Now, although a close approximation to this does clearly result from his Experiments, it is simply impossible that this can be a *general law of fluid motion*, as it would make the surface-velocity at a point *independent of the distance from the banks*, and therefore *constant right across a rectangular section*, which is contrary to fact in the latter case (*see Plate* IV. below, and *Plates* of Darcy-Bazin Report, *passim*).

Mr. Révy proposes this law, however, as a general law *only of Great Rivers*; but even for these his (published) experiments hardly warrant the conclusion that this is *other than a particular law*, or perhaps even only a local peculiarity.

The Result depends apparently (pages 114—119, and 143 of Révy Report) solely on two Series of Experiments,—one on the Paraná River, one on the Uruguay River:—in each of which the velocity-measurements were effected only at 9 different points (*see* his *Plate* V.), none of which were near the banks,—the nearest points to the bank being (by measurement of the scale)—

Paraná River:—930' from right bank, 460' from left bank. .....
Uruguay River:—100' from right bank, 150' from left bank. ..... }

Moreover these velocity-measurements were *not always at the positions of the Soundings*: and the soundings appear to have been taken *only on the Experimental Sections*, and may therefore not fairly represent the average depths for some distance above and below the section.

The only way in which Mr. Révy's proposed law can be conceived as a *general law* of open channels, is in channels whose bed and sides are of soft material, in which case it is quite conceivable that erosion will take place until the relation of depth to distance from banks is such that the surface-velocity may be simply proportional to the depth.

33. *Surface-Velocity Mean Curve in Solání Aqueduct.*—The form of the Mean Curves for the Chambers of the Solání Aqueduct was so strikingly regular, that they were selected for trial.

After various trials it was found that

b = half breadth of channel.

y = abscissa of any point on b (measured from centre).

u_o = central mean-velocity = max. ordinate.

u = mean velocity at any point whose abscissa is y
= ordinate of mean curve.

Then the following simple equation

would represent the actual mean curve of the observations to a high degree of approximation.

The three bottom lines of the "Series" Nos. 5, 6, 7, Tables II., III., show

(*a*), the mean velocities (at each point) by observation.
(*b*), the calculated values of the same as by formulæ (11).
(*c*), the discrepancies between (*a*), (*b*).

All these three Results (*a*), (*b*), (*c*), are also well exhibited graphically by the figures of *Plate* IV. in which

(*a*), the Mean Curve of observation is shown by a clear line.
(*b*), the Curve whose equation is (11) is exhibited by a dotted line.

It will be at once remarked that the discrepancies (*see* last line of each Series of Tables II., III., or *see* figures, *Plate* IV.) are all small, as shown in following Abstract:—

Table	Number Series	Number of Sets	Gauge-depth	Discrepancies between curve and formula
II.	5	15	8′·90 — 9′·05	Extremely minute in general.
	6	14	8′·75 — 8′·90	Mostly very small.
III.	7	16	8′·65 — 8′·80	Mostly small.

The discrepancies will be observed to be mostly

— in left half curve
+ in right half curve } of Left Chamber.
+ in left half curve
— in right half curve }

This shows that the 'Mean Curves' are not quite symmetrical about

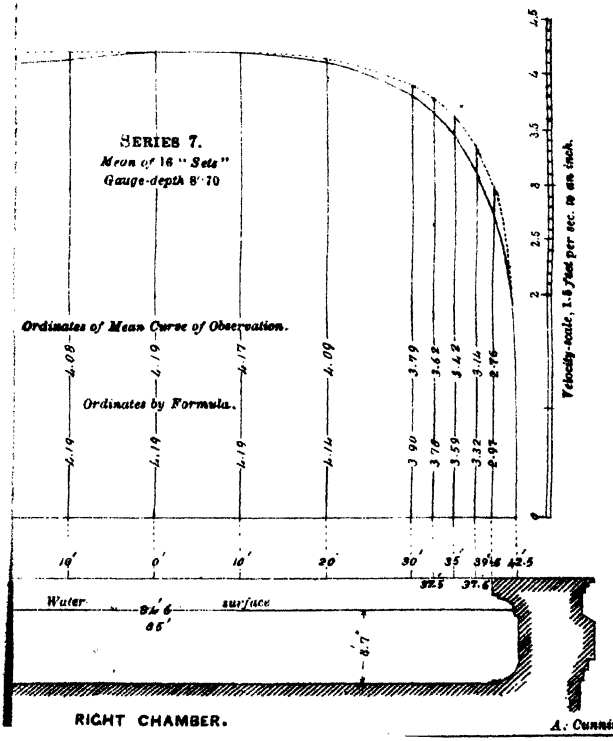
ULIC EXPERIMENTS AT ROORKEE.

SURFACE VELOCITY MEAN CURVE.

(At centre Cross-section of Solání Aqueduct).

EXPLANATION.

ions are figured on the Cross-sections to right and left of centre.
ordinates of all the Curves represent Velocities.
Mean Curves of observation are clear lines.
Curves of Equation $\frac{u^4}{u_0^4} + \frac{y^4}{b^4} = 1$, *are dotted lines.*
for Cross-sections and Abscissæ, 25 feet to an inch.
for Velocities (ordinates), 2·5 feet per sec. to an inch.



A. Cunningham, del.

mid-channel, which is probably due to the position of the two chambers with reference to the channel above and below them,—*see* Plan, *Fig.* 3 of *Plate* I.—and to their length (872′ = about $10\frac{1}{2}$ × width) not being sufficient for the motion to become quite similar to motion in a very long uniform channel.

The discrepancies are also on the whole larger,—

On the left side of the Left Chamber.
On the right side of the Right Chamber.

This is probably due to the *partial contraction* (nearly a foot) *of the "surface-width"* when the surface rises over 8′ 3″ above the bed (*see* Section, *Plate* IV.), as it did in all these Experiments.

[It would of course be possible to find a modified form of the Equation (11) which should more nearly represent the actual Mean Curves, but as the chief discrepancies explained above appear to be *local peculiarities*, it does not appear worth while to do so; the object of this inquiry being to discover laws of motion *in regular channels of great length*].

It will be noticed also, that the discrepancies are mostly extremely minute in the case of Series 5, *Fig.* 4, corresponding to a gauge depth of 8′·93 — 9′·05, and appear to increase as this depth decreases. This bears out the Remark that the form of the function (f) probably varies with the depth.

This curve may be called a "quartic ellipse"—from the resemblance of its equation to that of the common ellipse: it also resembles an ellipse in form, having the same vertices and tangents at the vertex as the ellipse (u, x being co-ordinates),

$$\frac{u^2}{u_o^2} + \frac{y^2}{b^2} =$$

but lying everywhere closer to those tangents, and therefore *outside that ellipse.*

Its area taken right across the channel represents the Surface-Discharge (D_o).

This is most conveniently found from the area of its projection formed by 'projecting' the curve so as to alter all the ordinates (u) in the ratio $b : u_o$, so that writing $x = \frac{b}{u_o} . u$ the equation of the projection takes the simple form

$$x^4 + y^4 = b^4$$

the area of which is most easily found from its polar equation

$$r^4 = b^4 (\cos^4\theta + \sin^4\theta)^{-1}$$
$$= b^4 \left\{(\cos^2\theta + \sin^2\theta)^2 - 2(\sin\theta\cos\theta)^2\right\}^{-1}$$
$$= b^4 \left\{1 - \tfrac{1}{2}\sin^2 2\theta\right\}^{-1}$$

Whence its Area $= \int_0^{\frac{\pi}{2}} r^2\, d\theta = \int_0^{\frac{\pi}{2}} b^2 (1 - \tfrac{1}{2}\sin^2 2\theta)^{-\frac{1}{2}}\, d\theta$

$$= \tfrac{1}{2} b^2 \int_0^{\pi} (1 - \tfrac{1}{2}\sin^2\phi)^{-\frac{1}{2}}\, d\phi, \text{ writing } 2\theta = \phi$$

$$= b^2 . \int_0^{\frac{\pi}{2}} (1 - \tfrac{1}{2}\sin^2\phi)^{-\frac{1}{2}}\, d\phi. \quad (\textit{See} \text{ Todhunter's Int. Cal. Art. 41}).$$

This definite integral is a *complete* elliptic function of first order whose modulus is $\frac{1}{\sqrt{2}}$: its value is known* to be 1·85407.....Hence

Area of projection = 1·85407.....b^2

and by the principle of projection

Surface Discharge $= \frac{u_o}{b} \times$ Area of projection

Hence

Surface Discharge = 1·85407 ... $u_o\, b$

= ·927 .. × Mean Central velocity × with of channel,..(12).

This interesting Result, that the surface velocity mean-curve in both chambers of the Solání aqueduct closely approximates to the simple geometric curve,

$$\frac{u^4}{u_o^4} + \frac{y^4}{b} = 1$$

is probably however only *a particular Result, i. e.*, that this Curve is peculiar to the case of—

"Rectangular Masonry Channel flowing about $\frac{8}{10}$ of its width deep",.....(13).

It would be interesting to continue this investigation under varied conditions, but in the present short course of Experiments these changed conditions could not be realized.

Such an Experimental investigation would be necessarily very tedious, as about 10 *working days* (*i. e.*, excluding windy days, rainy days, and holidays) are necessary to the accumulation of sufficient data for studying the geometrical form of *one Mean Curve.*

And suitable Experiments could hardly be made at all, unless the exigencies of Canal Administration would admit of the conditions (viz.,

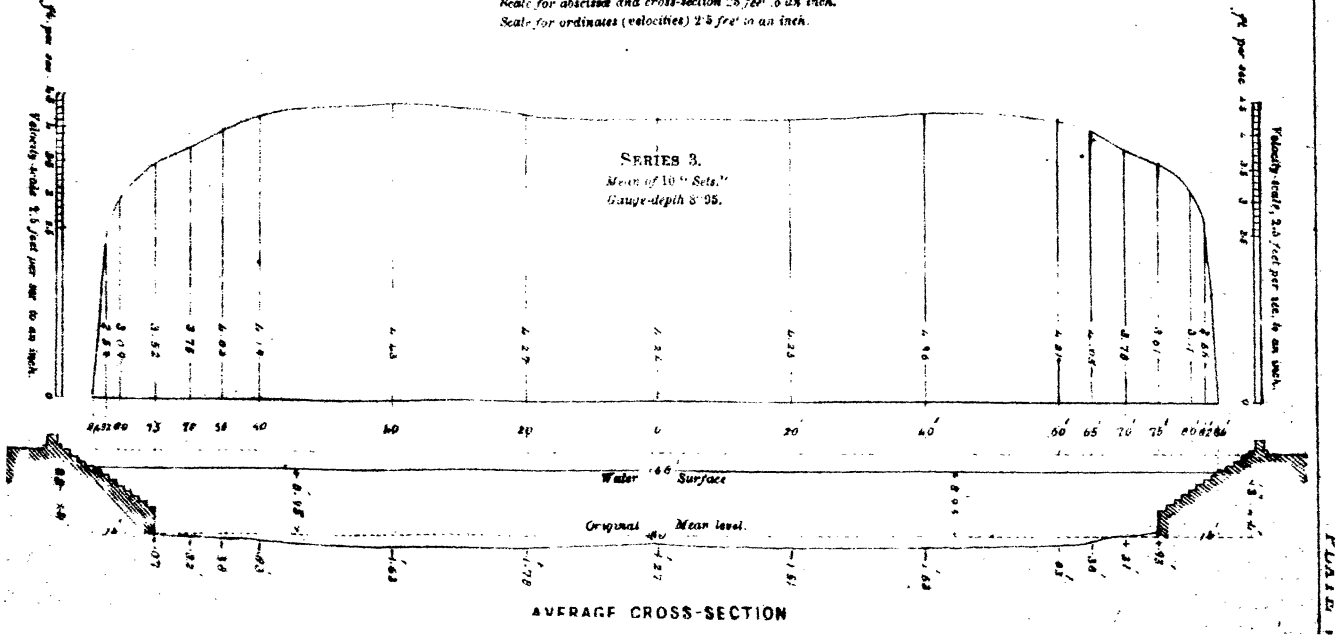
* *See* Encycl. Metr., Art. Definite Integrals, p. 529.

HYDRAULIC EXPERIMENTS AT ROORKEE.

SURFACE-VELOCITY MEAN CURVE.

(At Experimental Sections in Solání Embankment.)

Abscissæ indicate widths to right and left of centre.
Ordinates indicate velocities.
Scale for abscissæ and cross-section 25 feet to an inch.
Scale for ordinates (velocities) 2·5 feet to an inch.



AVERAGE CROSS-SECTION

PLATE I

depth of water) being maintained steady for at least (ten working days or say) a fortnight at one time, and then varied.

34. *Surface-velocity Mean Curve in Solání Embankment.*—*Plate* V. exhibits the Mean Curve resulting from Series 3 (Table I.) of Surface-velocity observations at the two experimental sections (Art. 11) in the Solání Embankment. The Series consists of 5 SETS of velocity-measurements at each section.

[The average cross-section in neighbourhood of each experimental section was found in the manner indicated in Art. 19. The resulting average sections were so nearly the same, that it seemed preferable to combine the two Series of 5 SETS at each section, so as to form a sufficient number to give a good average].

The Mean Curve so formed is strikingly symmetrical—even to its irregularities—about the centre line.

The most striking irregularity is the unusual feature of a wide-spread small depression about the middle, so that there are two lines of maximum-velocity about 40 feet to Right and Left of the centre.

This may be due to either of two following causes, or partly to both:—

1°. It is possible that the influence of the central pier of the Solání Aqueduct distant only 2860 and 3195 feet, respectively (*see* Plan, *Fig.* 1, or Art. 11) may be sensibly felt at this distance.

2°. The Average Cross-section (*Plate* V.) shows that the bed is decidedly shallower about the centre than for about 50′ on either side of it.

Either of these two causes separately might account for it; without a much more extensive series of experiments it seems impossible to assign it to either with any certainty. It is even possible that the moderate shallowing noticeable about the centre may itself be due to the action of the distant Pier of the Solání Aqueduct causing a deposit of silt above it.

[In consequence of the doubt as to the cause of the above hollow, it is not worth while attempting to discover the equation to this Curve.]

Two minor irregularities occur quite symmetrically in the form of slight depressions in the curve about 70′ to right and left of the centre. It seems probable that they are due to the proximity of the salient corner of the last step on either side, which produces an *abrupt* diminution of depth at 75′ on either side of the centre, and may begin to affect the surface motion first about 70′ on either side of the centre, more than the bed does, being actually *nearer to the surface* at those points than the bed under them is.

The great flatness of this curve is remarkable: the velocity being *barely*

less than the central velocity over a central space of three-fourths of the whole width: it is thus much flatter than the similar Mean Curves in the Solání Aqueduct.

35. *Marginal Surface-Velocity.*—This is a quantity of not much practical importance, as it is too small to sensibly affect measurement of Discharge: it is, however, of great importance in the Theory of fluid motion; unfortunately, it does not admit of direct measurement by any process yet known: and, indeed, with "Free Instruments," (*i. e.*, "Floats", *see* Article 12,) it is impossible to measure "velocity" close to the edge with any accuracy.

Many attempts were made to do this with "Floats", but they all failed from the same cause; the Floats invariably *deviated rapidly towards the centre*, and, therefore, entered into quickened stream-lines.

The following comparative Results were clearly established by a very large number of trials with small 1-inch floats, and with minute pieces of straw in the channels 168′ and 85′ wide at surface in both the Solání Embankment and Aqueduct.

(1). In a uniform channel the "velocity" in the surface stream lines near the margin *decreases very rapidly* with proximity to the margin, and at the edge itself is very small, and probably zero, ... (14).

(2). And there is a constant surface motion (deviation) from the edges towards the centre, most intense at the edges and rapidly decreasing with distance from the edges, ... (15).

It is easy to verify these Results by watching the motion of small particles of stick, straw, foam, &c., near the edge *of a uniform channel*, (*i. e.*, with straight edges for a considerable length): they will be found to bear out the above Results: in particular it will often be noticed that particles touching the edge often *cling to it for an appreciable time*, and when they do move, rapidly leave the edge.

It is interesting to remark that the equation of the surface-velocity Mean-Curve (Eq. 11., Art. 33) fully satisfies the requirements of Result (14).

[Messrs. Darcy and Bazin do not discuss this question: it may be seen incidentally, however, that they differed in opinion as to Result (14): for in two instances the surface-velocity curves are delineated in their Atlas (*see Plate* XVIII., *Fig.* 7, 8), and in these the marginal portions are drawn (free-hand) with ordinates which *are not extremely small.*

Any one plotting the surface-velocity curves from the figures, Tables of their numerous Experiments would probably *on first trial* be tempted to draw in the marginal portions (free-hand) with ordinates not extremely small, but it must be remarked

that *actual velocity-measurements* have been effected *proportionately much closer to the Edge*, in the present Experiments than in the Darcy-Bazin Experiments, as seen below :—

	Full Surface Width	Minimum distance from edge of actual Velocity -measurement	Proportionate minimum distance from edge
Present Experiments,	85'	about ·625 feet,	·00735 of width,
Darcy-Bazin Experiments,	2 metres	·03 metre,	·015 of width,

and that the comparative Results (14), (15) above, are based on Experiments *much closer still to the edge :* further the free-hand drawing of the marginal portions of the surface velocity-curves of the Darcy-Bazin Experiments may be perfectly well executed so as to satisfy the requirements of the Results (14, 15).

36. *Relation of central surface-velocity to depth.*—This is one of the most important inquiries in Hydraulics, especially in a running canal, for if the central surface-velocity corresponding to each depth be known at a given place, and if the relation between the central surface-velocity and mean velocity be also known, the MEAN VELOCITY could be found *from a simple observation of the gauge depth*, which would be a remarkable simplification of the ordinary labor of the Engineers of a running Canal as regards measuring Discharges.

Central-Surface velocities had been observed in large numbers in the course of these Experiments with range of depth varying from 5·9 to 9·7 in both Chambers of the Solání Aqueduct.

As a first step, the whole of these Surface-Velocity Measurements in the Solání Aqueduct were abstracted in Tables according to the varying 'gauge-depths' on the Standing Gauge; the state of the Wind being carefully entered against each entry. The Means of all the velocities under each 'gauge-depth' were then taken—without regard to the state of the Wind.

Velocity-curves were then drawn, the gauge depths being the abscissæ and the Means of velocities corresponding the ordinates.

The Curves so drawn were so irregular that *no conclusions could be drawn at all;* on examination, however, it appeared that the principal irregularities were due to Wind.

As the next step, all the observations made on windy days were struck out: this of course removed half the data: but the remaining data be considered good.

The Means of all velocity-measurements made in a calm, were next taken, and the Velocity-curves drawn as before.

These curves will be seen to be tolerably regular Curves—*see Plate* VI., most of the irregularities (due to Wind) have in fact disappeared.

As to the still apparent irregularities, it may be observed that the number of observations on which the several ordinates (velocities) depend is very different—*e. g.*, one ordinate depends on only 3, and another on 321, observations.

[As the fluid motion has been shown to be unsteady, so that only *average velocities* taken over a long time,—or in other words only means of a very large number of observations—are fairly comparable among one another, it is clear that those ordinates (velocities) which depend on only a small number of observations are not fairly comparable with the others.]

Excluding—or rather, attaching little weight to—these ill-determined ordinates, both Curves will be seen to be nearly regular, and to be *approximately straight*, *i. e.*, within the limits of the observations.

Another source of irregularity is that the observations from which these Curves have been plotted—not having been made for the express purpose of this investigation—were made without reference to the state of the Canal, viz., whether rising, steady, or falling at the time).

In order that the observations might be perfectly comparable *for the present purpose*, they should have been taken in equal numbers at each depth, and only when the Canal was in a steady state of level.

In seeking to represent these Curves by an equation, which shall therefore give the central surface-velocity as a function of the depth, it must be remembered that the velocity must necessarily vanish with the depth, so that the Curve must pass through the origin of abscissæ: on examining the figures this shows that the Curve must be *concave to the axis of x.*

This naturally sugests a parabola as a suitable form of curve: on actual trial it was found that the following parabolæ agree approximately with the Curves of observation *throughout the range of observation.*

$$\left.\begin{aligned} v_o^2 &= 2x \text{ for the Left Chamber,} \\ v_o^2 &= 1{\cdot}9x \text{ for the Right Chamber,} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (16).$$

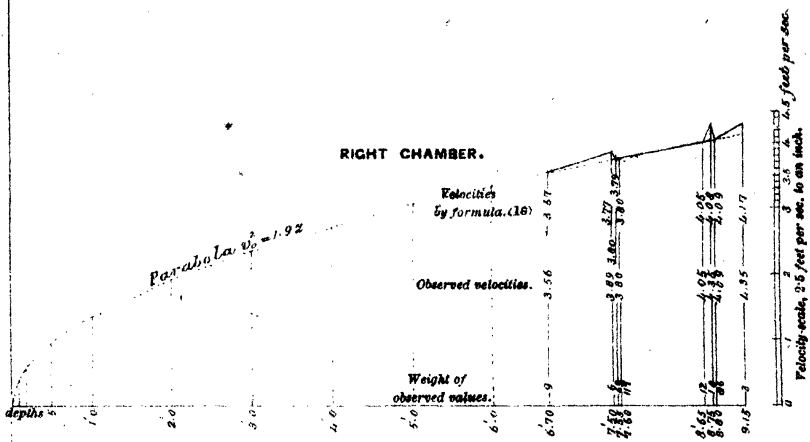
Plate VI. exhibits these Curves—(Curves of observation by clear lines, parabolæ by dotted lines): the gauge-depths (x) are figured below the Base line, and the WEIGHTS of observed values of ordinates—*i. e.*, the

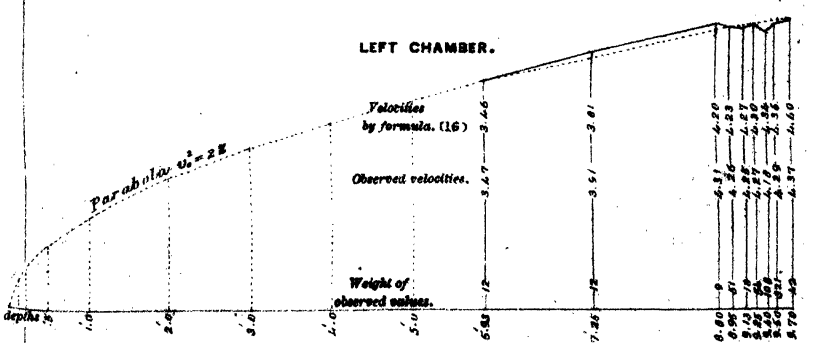
HYDRAULIC EXPERIMENTS AT ROORKEE.

CURVES OF CENTRAL SURFACE VELOCITY

at Centre-section of Solání Aqueduct.

Abscissæ represent depths on scale of 20 feet to an inch.
Ordinates represent velocities (v_s) on scale of 2·5 feet per sec. to an inch.





numbers of observations on which each observed ordinate (velocity) depends—above the Base line.

[Much confidence cannot of course be put in the correctness of the above Results (16) beyond the limits of the observations: all that can be said is that within these limits, which embrace however the most important practical range (5'·9 to 9'·7 depth)—the Result (16) nearly represents the observations *of calm days*.

But the convexity of the curves is so slight within this range that almost any parabolic curve $v_o = \sqrt[n]{p^{n-1}\, z}$ would suit nearly as well.

If instead of the 'depth' (z), the 'hydraulic mean depth' (R) be taken as the variable abscissa, it will be found that the common parabolæ whose Equations are

$$\left.\begin{aligned} v_o^2 &= 2{\cdot}48\ \mathrm{R} \text{ for the Left Chamber,} \\ v_o^2 &= 2{\cdot}44\ \mathrm{R} \text{ for the Right Chamber,} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16a),$$

also agree approximately with the Curves of observation *throughout the range of observation*.

The latter Results by which $v^2 \propto \mathrm{R}$ agree in form with the well-known formulæ (where U = mean velocity,

$$\mathrm{U} = {\cdot}8 v_o \text{ and } \mathrm{U} = {\cdot}92\sqrt{2\mathrm{R}i}, \text{ whence } v_o \propto \sqrt{\mathrm{R}} \quad \ldots\ldots\ldots\ldots (16b),$$

and also with the Darcy-Bazin Results by which (Darcy-Bazin Report, pages 12, 157)

$$\mathrm{RI} = \left(\alpha + \frac{\beta}{\mathrm{R}}\right)\mathrm{U}^2, \text{ and } v_o = \mathrm{U} + \mathrm{K}\sqrt{\mathrm{RI}}$$

whence may be easily deduced

$$v_o = \left\{\left(\alpha + \frac{\beta}{\mathrm{R}}\right)^{-\frac{1}{2}} + \mathrm{K}\right\}\sqrt{\mathrm{RI}}$$

where α, β, K are certain constants, and the quantity $\left(\alpha + \frac{\beta}{\mathrm{R}}\right)^{-\frac{1}{2}}$ is also sensibly constant *within the range of the present observations*, so that the $v_o \propto \sqrt{\mathrm{R}}$ within that range nearly].

36a. *Practical suggestion.*—The above suggests that in a running Canal, the labor of observation in measurement of Discharges at all places of permanent section (as in masonry channels), where there is also a permanent Gauge, might be altogether saved for the future by a really good series of measurements of central surface-velocity taken *on suitable occasions*.

This is a work which might readily be done by every Canal officer for his own division.

The following conditions should be attended to in selecting the occasions for the field work:—

NAWAB SALAR JUNG BAHADUR

1°. The air should be quite calm.

2°. The Canal should be *neither rising nor falling*, *i. e.*, the Standing Gauge should have been steady for at least one day preceding the measurement; and unless it remain steady throughout the following day, the observations *should be rejected* (as far as the purpose here proposed is concerned).

3°. The occasions most suitable for the purpose are when the Standing Gauge

marks *each successive quarter foot* of depth or thereabouts; thus three different days' work with gauge depths of say 6', 6'·25, 6'·5 would be far more useful than three days' work with almost coincident gauge depths, say 6', 6'·05, 6'·1.

4°. Opportunities with a very low Gauge-depth, or a very high one—satisfying Condition 2° above—would probably not be numerous: they should be utilized whenever they occur, as they are the most important of all in studying the shape of the Curve.

5°. The observations should be made with all practicable accuracy, and, if possible, *all by the same person*, (not only on each occasion, but on all the occasions).

6°. To secure a good *average value* of the velocity, at least 50 observations should be made at one time; the mean of these would be considered the *average central surface velocity due to the particular depth at the time for a calm day.*

These mean velocities should be plotted so as to form a Curve in the manner explained above, (similarly to the Curves of *Plate* VI.) It is unnecessary for the practical purposes of a Canal Engineer to try to form an algebraic equation for the Curve.

To estimate the Discharge in future at that place, it would suffice to read accurately the gauge-depth *on a calm day when the Canal was neither rising nor falling.*

The Curve, already laid down, would indicate sufficiently by its ordinates the Average Central Surface Velocity.

[It is improbable that any observations hitherto made, not with a view to the express purpose here proposed, would be accurate enough for this purpose.

The Author obtained* *all the recorded observations now available* in the Northern Division, Ganges Canal Office; these consisted of only—

18 velocity-measurements in both chambers of the Solâni Aqueduct,
33 ditto at Belrah, lower down the Canal,

taken at odd times by different observers, extending over several years, and *in all states of wind.*

Each separate "velocity-measurement" is believed to be the mean of only five observations, and is therefore a very poor measurement of "average velocity," even when made in a calm.

The Curves corresponding to each locality were plotted, as before explained, and were found to be so irregular as to warrant the belief just stated, that previous observations could not be utilised for this purpose].

* From the Executive Engineer, Capt. J.H. Western, R.E.

CHAPTER III.

SUBSURFACE-VELOCITIES.

37. Subsurface Floats.—For measurement of "subsurface-velocity" no "Free Instrument" (Art. 12—II.) yet tried can be said to be thoroughly satisfactory. The "Free Instruments" intended for this purpose may be roughly classed as "Instruments of direct observation", and "Instruments of indirect observation", their respective aims being—

i. INSTRUMENTS OF DIRECT OBSERVATION, } To measure "velocity" at a known depth *by direct observation*.

ii. INSTRUMENTS OF INDIRECT OBSERVATION, } To furnish data from which the "velocity" at a certain depth *may be deduced* by calculation.

38. INSTRUMENTS OF "DIRECT OBSERVATION".—These consist essentially of a mass of tolerable size submerged (by its own weight) to the depth at which it is desired to measure velocity, and connected by a fine wire or thread to a small "surface-marker".

The difficulties in the way of designing a suitable instrument are that an attempt has to be made to satisfy several conditions of a really inconsistent character. The essential conditions are in addition to the previous six (Art. 12—II.)—

7°. The submerged mass must be of sufficient *mean specific gravity*—
(*a*), to sink rapidly to the depth intended.
(*b*), to retain itself at that intended depth.

8°. The submerged mass must be prevented from sinking beyond the intended depth by a "surface-float" to which it is joined by a very fine wire or thread.

9°. The exposed surface of the "surface-float" and "connector" must be so small that the action of the current on them may be *fairly negligible* in comparison with its action on the submerged mass.

10°. The materials should be such that the several matters of adjustment (7°, 8°, 9° above) are very little affected by variations of dryness and moisture.

The most important condition of all in an Instrument of "direct observation" is No. 9° (above), as unless this condition is satisfied the Instrument cannot fairly be called one *of direct observation*.

It will, however, be obvious that conditions 7° and 9° (above) are *es-*

sentially inconsistent, and can therefore only be partially satisfied by a compromise. The practical difficulties in the way of satisfying these (7° and 9°) sufficiently nearly, as well as condition 10°, and also the conditions of strength and cheapness (5° and 6° of Art. 12) were found very difficult to fulfil.

When all the conditions are tolerably satisfied, it may be fairly assumed that the Instrument will yield a measure of the

"Average 'velocity' along its line of motion at the depth at which its centre is sunk".

Two descriptions of this class of Instrument were tried: these will be styled for brevity the

(1). Subsurface "SINGLE BALL" or simply "BALL",—for description, &c., *see* Art. 40, *et seq.*

(2). Subsurface "TIN"—for description, &c., *see* Art. 44, *et seq.*

39. INSTRUMENTS OF INDIRECT OBSERVATION.—In these it is sought to measure certain data from which the "velocity" at a given depth may be deduced by calculation, these data being such that the Instrument need not fulfil the almost impracticable conditions 7°, 8°, 9°, 10°. A serious objection to such use is that the deduction of velocity *from indirect data* can only be done *by assuming a law* of relation between pressure and velocity of current fluid. The law of this connexion however is probably not known with sufficient accuracy to make it *the basis* of so important a research as the law of velocity-variation in current fluid.

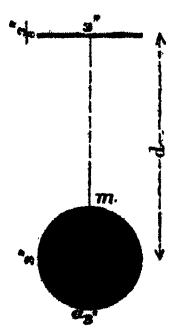
Two descriptions of this class of Instrument were tried: these will be styled for shortness the

(1). Subsurface "TWIN-BALLS"—for description, *see* Art. 48, *et seq.*

(2). Rods—for description, *see* Art. 68, *et seq.*

40. Description of Subsurface "Ball".—A spherical Ball of 3″ diameter was carefully turned (in a lathe) of heavy wood—(Hind. "Khair", *Acacia Catechu*)—specifically heavier than water: the 'surface-float' consisted either of a disc of English deal 3″ diameter and $\frac{3}{8}$″ thick, or of a slice of cork (part of a 'bung') about 2″ diameter and $\frac{3}{8}$″ thick.

Fig. 6.



The two were connected by an *extremely fine* brass wire (No 30, Birmingham Wire Gauge, weighing *only* 2·44 *grains per foot*): the ends of the wire were passed, one through a hole in the middle of the 'Surface-float', the other

through a fine hole, bored right through the "Ball", and were then each wound twice or thrice round a tiny splinter of wood, which sufficed to prevent the wire returning through the hole.

The 'Ball' and 'Surface-float' were made always of the sizes above indicated, but the weight of the 'Ball' was adjusted—by Experiment in still water—so as to sink its 'surface-float' almost to the water's edge:—thus, if any 'Ball' proved to be too heavy for its floats, some of its mass was removed by boring a cylindrical hole at the end *m*, and if any 'Ball' proved too light, lead was countersunk into it at the end *a* until the desired adjustment was effected.

The cost of this Instrument was about 6 annas.

41. *Handling of the subsurface 'Ball'.*—The use of a wire caused special difficulties in handling. It was found essential never to let the wire fall slack, as when slack it commonly 'kinked', and the 'kinks' proved to be points of excessive weakness; many balls were lost owing to the wire breaking at a kink.

To keep the wires straight the Instruments were kept lying stretched at full length on a common bamboo framework (Hind. 'jáfarí') with rough fittings to receive the Balls and Floats. There was a similar 'framework' in each Boat. The men who handled the Instruments were drilled to handle them in such a way as never to let the wires fall slack. Of course care was necessary to do this properly in a stream running at 3 miles an hour, but after a little practice it was found that—delicate as the Instrument may seem from the description—it would bear a good deal of use with moderate care.

[There was a small daily loss due partly to breakage of wires, partly to difficulty in catching the float at the instant of passing the lower Boat, partly to absorption of water by the Ball causing it to sink out-right.]

42. *Practical objections to the use of wood.*—It has been explained that each 'Ball' and its 'surface-float' had to be specially adjusted by experiment, no two specimens of wood being exactly similar. It will be understood that in the endeavour to satisfy the contradictory conditions 7° and 9°, (Art. 38,) this adjustment was rather delicate: it was soon found that the specific gravity of wood varies so much by exposure to dryness and moisture—to the extremes of which these Instruments are necessarily exposed in their ordinary use—as to render any fine adjustment useless: thus, after the original adjustment had been completed in still water, it was found that after one day's drying in the air, many of the Balls became too light to sink at all until after prolonged immersion; and, on the other hand, after prolonged immersion (*e. g.*, during actual use) some of the Balls became so heavy as to sink altogether along with their float, and were thus lost.

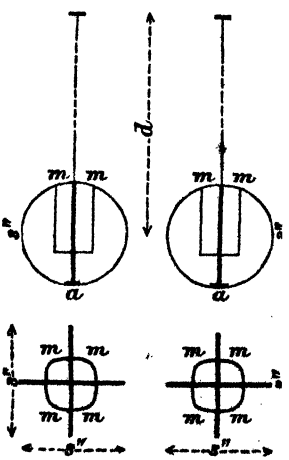
These difficulties—not at first anticipated—were to a considerable extent obviated by boiling the Balls for some hours in linseed oil, after which they ceased to be so affected by variations of dryness and moisture.

43. It is considered—as the Result of several thousand experiments with the "Single Ball", that this Instrument sufficiently *fulfils all the general conditions* 1° to 6°, (Art. 12—II.,) for a "Free Instrument", and that it also *fulfils the special conditions* 7°, 8°, and to a lesser extent 10° necessary for an "Instrument of direct observation", but that it does not sufficiently fulfil (as here constructed) condition No. 9°, the most essential of all for an "Instrument of direct observation"; that is say, *the exposed surface of the 'surface-float' is not so small* that the action of the current on it is *fairly negligible* in comparison with its action on the submerged Ball.

Improvement suggested.—The experience gained points to the substitution of metal for wood for the material of the Ball, and to cork (or some lighter* material) for the surface float.

44. Description of the Subsurface "Tins."—Two circular discs, each 3″ in diameter, were cut out of the thinnest sheet tin: a radial slit of $\frac{1}{32}$″ was cut out of each: the discs were then slid across one another so as to have a common diameter (each disc being passed through the slit in the other) with their planes at right angles, and were then slightly soldered together in this position, at one end marked *a* in figure.

Fig. 7.



The 'Surface-float' consisted simply of a thin slice of a cork—(such as is used for soda-water bottles)—*not exceeding* 1″ *in diameter nor* $\frac{1}{4}$″ *in thickness.*

The two were united by a fine silk thread tied through a hole close to the edge of one of the two discs at the unsoldered end (*m*), and of the common diameter (*ma*).

To enable so small a 'float' to be used, the angular spaces (*m*) between the tin discs were filled up with cork massed at the end (*m*) where the thread was tied, and retained in position by fine

* Pith (Hind. "shola") was tried, but was found to be too absorbent and too fragile.

wire; the quantity of cork being adjusted—by experiment in still water—so that the combined weight of the tin discs and appendages were just buoyed up by the small 'surface-float'.

The object of placing the extra cork at the end (*m*) (where the thread was tied), and the solder at the other end (*a*) of the common diameter *ma* of the tin discs, was to cause that diameter to preserve *a vertical position*.

The cost of this Instrument was about 2 annas.

[This Instrument is quite similar in principle to that described at page 252 of the Mississipi Report, as having been used for some of the most critical observations: the size there described was, however, 2″ high by 8″ wide, which is (in the Author's opinion) too large for small streams, and for Experiment not near mid-channel of large streams].

45. *Handling of the subsurface "Tin".*—This instrument is very simple and convenient in actual use. It was found sufficient when not in use to wind the silk thread round the hollow spaces between the tin discs, and unwind it just before dropping into the water, care being taken to prevent its tangling whilst running out.

The adjustment of the Instrument is so delicate—in consequence of the very small size of the 'surface-float'—that it was found necessary to have the whole of the cork and thread thoroughly wet before beginning actual experiments.

46. It is considered—as the Result of 156 experiments with the subsurface "Tin"—that this Instrument sufficiently *fulfils the general conditions* Nos. 1, 2, and 4, 5, 6 of Art. 12—II. of a "Free Instrument"—and that it also *fulfils the special conditions* 7*a*, 8, 9, 10 (Art. 38) necessary for an "Instrument of direct observation", and in particular that it *fulfils the most important Condition* (No. 9°,) of such an Instrument to *probably the greatest extent that is practically possible;* but that it *does not sufficiently well fulfil* the important Conditions No. 3 of Art. 12—II., and 7*b* of Art. 38, and that it cannot therefore be trusted. This will be understood after reading the details of the "comparative experiments" (Art. 55) on the different kinds of Instruments.

47. *Hydrometer.*—The difficulties met with in constructing a good Instrument "of direct observation," have been obviously due to the presence of the Surface-float necessary to prevent the submerged mass sinking outright. It was thought that a suitable Instrument might perhaps be

somewhat on the model* of the 'spirit hydrometer', without any surface-float at all.

A hollow copper ball was constructed with a tube along one of its diameters through which a slender stiff wire could be slid. The ball was loaded with lead (inside) sufficient to make it float with the stiff wire (which corresponded to the stem of a spirit hydrometer) vertically in still water. The design was however abandoned for following reasons:—

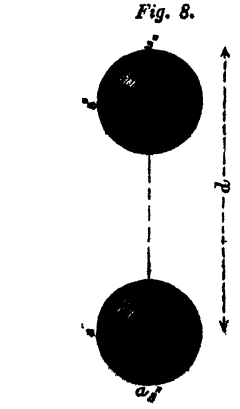
1°. The wire intended to project above thesurface to serve as a "marker" must be straight throughout its length: a wire of sufficient stiffness to retain its straightness in a length of 9½' during the somewhat rough handling of lifting in and out of the Boats must be stout, and therefore heavy, and will also expose considerable surface to the current in its length of 9½'.

2°. And will, therefore, require a large and heavily weighted hollow ball to carry it in a nearly vertical position when exposed to the current.

3°. The Instrument when in the current will be in a state of *very small vertical stability*, and will bob up and down a good deal before attaining its final position of equilibrium.

48. Description of the† "Twin-Balls".—Two spherical Balls of 3″ diameter were carefully turned (in a lathe),—one of a light wood (Hind. "Sissú", *Dalbergia Sissoo*)—one of a heavy wood (Hind. "Khair", *Acacia Catechu*). The two were connected by an extremely fine brass wire (of same size as described in Art. 40, and fastened off as there described).

Fig. 8.



The two Balls were made always of same size (3″ diameter), and were brought to nearly same conditions of surface smoothness: the weight of the heavy Ball was adjusted by experiment in still water—by countersinking lead into its lower end (a); so as to sink the upper Ball to about $\frac{1}{8}$″ from the water-surface.

The use of *wooden* Balls was of course subject to the same practical objections as described in Art. 42: these were similarly to a great extent obviated by prolonged boiling in linseed oil.

* Suggested by Dr. Murray Thomson, F.R.S.E., Professor of Experimental Science, Thomason C.E. College, Roorkee.

† This Instrument is recommended in several Works on Hydraulics, *e. g.*, Neville's Hydraulic Tables, Formulæ, &c., 2nd Ed., p. 25; Weisbach's Mechanics of Machinery and Engineering, Art. 370.

The use of a wire caused the same practical difficulties as described in Art. 41: these were successfully met in the same way as there described.

49. *Theory of the "Twin-Balls".*—As the utility of this Instrument depends *entirely on the legitimacy* of the Theory* by which the subsurface-velocity is to be deduced from the data furnished, and as its manner of use depends also on the requirements of the Theory, it will be well to examine the latter first.

It is assumed that the action of the current on the connecting wire is so small as to be fairly negligible in comparison with its action on the two Balls.

When the two Balls fall—as they usually will—into fluid strata of different velocities, one Ball must clearly move faster, and one slower than the fluid in which they are respectively immersed. It follows that the fluid accelerates one and retards the other; its action on either consists partly of direct pressure and partly of friction (or adhesion).

Let a = cross-sectional area of either Ball,
v_o = "velocity" of fluid in which upper Ball moves,
v = velocity of fluid in which lower Ball moves,
u = common velocity of the united pair,
} at the same instant.

P_o, P_1 = Direct Pressures (‖ to axis of stream) of fluid on upper and lower Ball.

$F_o F_1$ = Friction (‖ to axis of stream) of fluid on upper and lower Ball.

k, λ, μ are certain "constants" depending solely (a) on the nature of the fluid, (b) on the state of the surfaces of the Balls, (c) on the shape of the the Balls, and which have therefore *the same value for both Balls*, because the Balls are supposed to be of precisely similar shape and state of surface.

$(v_o - u)$ = relative velocity of upper Ball and fluid.

$(v - u)$ = relative velocity of lower Ball and fluid.

Now, according to the best experimental Results at present known as to "Pressure" and "Friction" of currents on solid bodies floating in them—

$$P_o = k\,(v_o - u)^2 \,.\, a\,;\; P_1 = -\,k\,.\,(v - u)^2 \,.\, a, \ldots\ldots (17a),$$

* No explanation of this is given in the Works quoted as recommending this Instrument.

$$F_o = \left\{\mu + \lambda . (v_o - u)^2\right\} a\,; \quad F_1 = \left\{\mu + \lambda . (v - u)^2\right\} . a, \ldots\ldots (17b).$$

[*See* Rankine's "Manual of Applied Mechanics", 3rd Ed., Art. 652,—for Results as to "Pressure", and Poncelet's "Introduction à la Mécanique Industrielle," Arts. 387, 388, for Results as to "Friction"].

And, when the "Twin-Balls" have attained a state of relative equilibrium, and are moving with a uniform velocity, it is clear that the Resultant Fluid Action on them must be zero, *i. e.*,

$$P_o + P_1 + F_o + F_1 = 0, \ldots\ldots\ldots\ldots (18),$$

$$\text{whence } (k\,a + \lambda\,a) . \left\{(v_o - u)^2 - (v - u)^2\right\} = 0,$$

$$\therefore (v_o^2 - v^2) - 2u\,(v_o - v) = 0,$$

$$\text{or } (v_o - v) . \left\{(v_o + v) - 2u\right\} = 0,$$

whence, as $(v_o - v)$ is not generally zero, it follows that

$$v_o + v - 2u = 0,$$

$$\text{and } v = 2u - v_o, \ldots\ldots\ldots\ldots (19),$$

so that, if *simultaneous values* of the common "velocity" (u) of the "Twin Balls", and of the "velocity" of the fluid (v_o) in which the upper moves can be obtained by direct observation, Result (19) furnishes at once the sought "velocity" (v) of fluid in which the lower is moving.

The preceding Theory is probably the best obtainable at present, and the simplicity of the Result—

$$v = 2u - v_o, \ldots\ldots\ldots\ldots (19a),$$

leaves nothing to be desired. Its successful application requires, be it observed, that the quantities k, λ, μ, a be *sensibly the same* for both Balls which involve that—

"The submerged portion of both Balls should be sensibly alike in all respects of *shape*, *size* and *state of surface*," ..... (20).

Now, it is practically impossible that the upper Ball should be completely submerged, as unless some small portion of it be permanently above the water, the Instrument, *as a whole*, will have no buoyancy whatever, and will certainly sink. The projecting portion may, however, be *very small* (say $\frac{1}{8}''$ in still water). It is, moreover, difficult to make the surfaces such as to be always of sensibly the same state of roughness; (especially when wood is the material used).

It is believed, however, that on the whole, the practical conditions above can be tolerably well complied with, and that the Instrument also satisfies all the general conditions (1° to 6° of Art. 12—II.) of a "Free Instrument".

50. *Use of the "Twin Balls".*—The Theory requires the *simultaneous observation* of the 'velocity' (v_0) of the fluid in which the upper Ball moves, and of the common 'velocity' (u) of the pair of Balls. Were the motion of the fluid what is technically termed STEADY (Art. 23), it would be of little importance whether these two quantities were given by simultaneous observations or not; but, in consequence of the fact of the motion of the fluid being decidedly UNSTEADY, (*see* Art. 25,) this Condition—that the two observations—for determining v_0 and u—be simultaneous, becomes *of more importance than all the others.* It is probably impossible to fulfil this Condition properly: the following was the mode actually adopted to endeavour to secure it.

Along with the "Twin Ball" a "Surface-float" was always dropped into the water from the upper boat at such an interval (either before or after) that they passed under the upper rope nearly together, and were therefore *running across the standard "Run" at the same time,* although not quite together, and indeed very seldom exactly along the same line of motion.

In this way, it is believed that the nearest approximation possible to the desired simultaneity of observation was obtained.

51. As the Result of many experiments with the "Twin Balls", it may be said that it fulfils all the general conditions of Art. 12—II. of a "Free Instrument", but that it is doubtful whether it is possible to carry out properly the requirements of the theory on which its use depends, thus—

(*a*), the practical impossibility of completely submerging the upper Ball unduly exaggerates the effect of the Subsurface current on the lower Ball.

(*b*), the impossibility of making the observations of the "Twin-Balls" and their accompanying surface-float truly simultaneous, or even quite in the same vertical plane, makes the Results yielded somewhat irregular.

And, after all, its utility depends on the correctness of that Theory.

52. Depth of submerged Mass.—One of the most important conditions necessary to the successful use of all these Instruments ("Single Ball", "Tin", "Twin Balls") is No. 7*b* of Art. 38.

"The submerged mass should be of sufficient mean specific gravity to retain itself *at the intended depth,*".....

as unless it do so, the depth of the velocity-measurement effected by its means would be quite uncertain.

It is necessary, therefore, to establish confidence on this point.

On first immersion (at the Boat) the connecting wires or threads are of course unstretched, and the surface-float moves uncontrolled by the subsurface-mass: but after a time, as the latter sinks, it stretches the connecting wire; the moment of its doing so is easily recognised from the bank by the jerk it gives the surface-float; after which the jerking of the surface-float is continued for some time, gradually diminishing however until the state of relative equilibrium is obtained. The Boat was placed at a distance from the Upper Rope (usually 100′ (*see* Art. 17,) which was believed to be sufficient to admit of this state of relative equilibrium being established.

The real depth of the subsurface-mass would not however be thus certainly known. To test this point, the Instruments were (before use for actual velocity-measurement) usually tested from the Pier of the Solání Aqueduct by being run along close to the vertical sides of the Pier.

The water was frequently clear enough to admit of the subsurface-mass being watched whilst sinking to a depth of over 6′ (judged by the fact of a 7′-wire being stretched). Within and up to this depth of immersion, the visible "lead" or "drag" of the subsurface-mass before or behind its attached surface-float never exceeded a few (about 4) inches even at the greatest depths, and was *less at lesser depths.*

This small displacement of the connecting wire from the vertical is a quantity really negligible, in its effect on the depth of immersion, which may therefore generally be considered as sensibly the same as the length of wire from top of surface-float to centre of submerged-mass.

[This preliminary Test was unfortunately not rigidly carried out in every case, its importance not having been from the first foreseen: notably it was not applied to the Subsurface "Tins"; these were, however, rejected after a few trials, detailed in Art. 55.

This particular difficulty—that of ascertaining definitely the depth of immersion of the submerged mass—is the most important of the objections pointed out by Mr. Révy (pages 5—7 of Révy Report) to the use of Subsurface-floats: it is, however—in the Author's opinion, after this season's experience—certainly not a sufficient objection in the case of Canals and small Rivers, though in the case of Great Rivers, the difficulty would be much aggravated].

53. Comparative Experiments on Subsurface-Instruments.—The whole of the early measurements of Subsurface-velocity in these

Experiments were made with the subsurface "Single Ball"; the "velocity-curves" resulting from its use were however so flat, (*see Plate* VIII.,) that it seemed doubtful whether the most essential condition 9° (of Art. 38), for an Instrument of direct observation was sufficiently complied with:—thus it will be evident that the action of the surface-current on the surface-float will partially mask the action of the subsurface-current on the sunken Ball, thus causing

(*a*), subsurface-velocities which are really quicker than the surface-velocity to be *under-estimated.*

(*b*), subsurface-velocities which are really slower than the surface-velocity to be *over-estimated,*

and thereby, of course, flattening the whole of the "velocity-curve". It was therefore deemed advisable to compare the Results given by it with those given by other Instruments.

The Instruments selected for comparison with it were—

(*a*). The Subsurface "Tin", as fulfilling in the highest degree possible the particular condition (9°) in which this Instrument was supposed to be deficient.

(*b*). The "Twin Ball", as purporting to afford data from which the effect of action of surface-current could be eliminated.

54. *Tediousness of comparative experiments*.—It has been explained (Arts. 25, 26) that in consequence of the *unsteadiness* of fluid motion non-simultaneous experiments are not fairly comparable, and also that really simultaneous Experiments are *generally* impracticable. It follows, therefore, that in comparing the indications of different Instruments, the only Results that are fairly comparable are the averages of a very large number of velocity-measurements *under external conditions as nearly as possible similar*. This of course makes such comparisons very tedious.

55. *Comparison of Subsurface "Balls", "Tins", and "Twin-Balls".*—The difficulties in designing a good Subsurface-float have been explained Art. 38, *et seq.*

The main difficulty is, of course, the elimination of the effect of the surface-current on the surface-float.

The above Instruments, in which an attempt to meet these difficulties was made in different ways, were compared as follows:—

The instruments were all made so as to expose the same area, 3″ × 3″, to the Stream—(*vide* Description, Arts. 40, 44, 48 of each)—both directly and laterally, so as to present them all to as nearly as possible the same subsurface action.

To render this Test as crucial as possible, the three Instruments were first applied to measuring velocity only near the bottom where the actual velocity is least, so that the difference of action of the surface-current and subsurface-current might be as marked as possible.

Cæteris paribus, that Instrument which gave *the lowest measurement* of subsurface-velocity (near the bottom) would be considered the one by use of which the effect of surface-action was best eliminated.

Of the two Instruments the "Balls" and "Tins"—(*see* Description, Arts. 40, 44) the latter—having much the smaller surface-float—might be expected to give Results *most free from surface-action*, *i. e.*, lower values of the subsurface velocity.

With the Current running about 7′ deep, the three Instruments were all adjusted to a depth of 6′ in still water.

156 of each kind were then passed down the 50′ "Run" in mid-channel of the Right Chamber, Solání Aqueduct, as rapidly as possible, always in the following order—

"One 'Ball', one 'Tin', one 'Twin Ball'"—

to secure as nearly as possible the same external conditions during observation of the three Instruments.

The "Run" was chosen in mid-channel, because the inevitable "deviations" of the Instrument to right or left of this line would on this line least affect their velocities.

Table IV. exhibits the Results—viz., the means of 13 different "Sets" of 12 observations with each instrument: the observations were made, 6 by each observer (R., W.), so that in the printed means, the personal equation is eliminated.

As might be expected, the "Twin-Balls" moved in every case with the highest velocity (*see* Table) and—after elimination of surface action—gave in each case *the lowest measure* (*see* Table) of the Subsurface velocity (at 6′ deep). And—contrary to expectation—the "Tins" moved generally quicker (*see* Col. 7 of Table) than the single "Balls", notwithstanding the minuteness of their surface-float, and the consequent minute effect of surface-current on their motion. This unexpected effect can only be due to one or other of the two following causes, or to both combined.

(*a*). This Instrument (the Subsurface Tin) does not satisfy Condition 3, (of Art. 12—II.): thus even if the common diameter of the two tin discs continue in its proper vertical position, the Instrument will expose an area varying

TABLE IV.

COMPARISON OF SUBSURFACE FLOATS.

Serial No.	1	2	3	4		5			6		7		Remarks.
	Date.	Gauge-depth.	No. of Experiments.	Velocities.		Velocities at 6′ deep.			Wind.		Difference of Velocity at 6′ deep.		
				3″ Twin-Balls.	Surface Floats.	By Twin Balls.	3″ Single Balls.	3″ Tins.	Direction.	Velty. feet per sec.	By Single Balls and Twin Balls.	By Single Balls and Tins.	
Series 1.	8-3-75	6·60	12	3·19	3·39	2·99	3·01	3·15	S E	10	— ·02	+ ·14	
	9-3-75	7·05	12	3·38	3·93	2·83	3·29	3·27	N W	5	— ·46	— ·02	
	„	„	12	3·28	3·91	2·65	3·21	3·35	N W	5	— ·56	+ ·14	
	„	„	12	3·37	3·90	2·84	3·34	3·28	V	10	— ·50	— ·06	
	„	„	12	3·41	3·92	2·90	3·32	3·28	V	10	— ·42	— ·04	
	10-3-75	7·50	12	3·46	3·86	3·06	3·34	3·41	..	..	— ·28	+ ·07	
	„	„	12	3·60	3·92	3·28	3·36	3·43	..	..	— ·08	+ ·07	
	„	„	12	3·62	4·03	3·21	3·45	3·44	N	8	— ·24	— ·01	
	„	„	12	3·48	3·97	2·99	3·39	3·56	N	8	— ·40	+ ·17	
	11-3-75	7·55	12	3·50	3·83	3·17	3·40	3·44	..	..	— ·23	+ ·04	
	„	„	12	3·50	3·67	3·33	3·30	3·56	..	..	+ ·03	+ ·26	
	„	„	12	3·53	3·84	3·22	3·40	3·49	..	..	— ·18	+ ·09	
	„	„	12	3·41	3·76	3·06	3·46	3 35	..	..	— ·40	— ·11	
Means, ..		..	..	..	..	3·04	3·33	3·38	..	..	..	..	

Each SET of 12 observations consists of 6 by each Observer combined so as to eliminate "personal equation".

from a 3″ circle to an ellipse with axes $3'' \times \frac{3''}{\sqrt{2}}$ *i. e.*, $3'' \times 2''$, nearly; but if the common diameter of the tin discs should not preserve its proper vertical position, the effective exposed area will become *still more reduced* and possibly enormously reduced (according to the tilt of the common diameter of the tin discs).

(*b*). The mean specific heaviness of the Subsurface-mass (the tin discs with the masses of cork, &c.) is not sufficient to retain it at full depth—in which case it would *rise into a higher* (and therefore a quicker) stream-line.

It will be remarked, that the differences between the Results of the single "Balls" and "Tins" are *not very large* (*see* Col. 7) in no case exceeding ·15 out of 3·50: but this must not be regarded as an unimportant difference; the fact is, that the Total variation of the Velocity from surface to the selected depth (6′) is so small (not exceeding 1·26 out of 3·91, even by the Instrument which most magnifies it), that this discrepancy of ·15 becomes very important. The conclusion is clear that—

"The Subsurface Single "Ball" is a better Instrument than the Subsurface "Tin",.....

The values of the Subsurface-Velocity as given by the "Twin Balls" are (with one exception) *all markedly less* than those given by the "Single Balls". It should be particularly observed that the greatest differences (·46, ·56, ·50, ·42, ·40,) all occur with a wind more or less down-stream, and the least difference (·02) with a wind somewhat up-stream, and that this is the very effect that might be expected, if it be admitted that all effect of surface-current is eliminated from the reduced value of subsurface-velocity given by the "Twin-Balls".

[Thus a down-stream wind would quicken the surface-current, and thereby increase the velocity of the Single "Ball", and an up-stream wind would have the opposite effect; and these are the very effects exhibited by the Experiments].

It does not, however, therefore necessarily follow that the "Twin Balls" is a more trustworthy Instrument than the single "Ball", because (*see* Art. 50) the value of the subsurface-velocity given by the "Twin-Balls" is dependent on the admissibility of the manner of reduction of that velocity, and moreover no *single value* of subsurface-velocity deduced from it would be really reliable on account of the impossibility of making the observations with the "Twin-Balls", and its accompanying surface-float, really simultaneous as required by the Theory.

Further comparative Experiments therefore seemed desirable.

56. *Further Trial of Subsurface Instruments.*—Most of the Experiments with Subsurface Instruments were carried out with at least two different sorts of Instruments, so as to continue the comparative Test. The Instruments compared were "Single Balls", "Twin Balls," and "Rods"—(the description, theory, and use of the latter will be found in Art. 68, *et seq.*)

The detailed Results of Experiments with the different Instruments are printed in separate Tables (Tables V.—XII.), but for facility of reference the same Serial Number is given to Series of Experiments with different Instruments *conducted at same time*, a distinguishing letter being added (B. for "Single Ball," BB. for "Twin Balls", R. for Rods) to indicate the Instrument employed.

Four such comparative Series were conducted, viz.:—

Table	Serial Nos.	Number of "Sets" of velocy-measurements in a Series.	Gauge-depth	Instruments compared
V., X.	10 B., 10 R.	4	5'·90—5'·95	Single Balls, Rods.
V., X.	11 B., 11 R.	12	7'·25	Single Balls, Rods.
VI., XI.	12 B., 12 R.	20	7'·55—7'·65	Single Balls, Rods.
VIII., IX.	14 B., 14 BB., 14 R.	20	9'·25—9'·50	Single Balls, Twin Balls, and Rods.

The Instruments were prepared in sets of 1′, 2′, 3′, 4′, 5′, 6′, 7′, 8′, 9′, depth of immersion, and *were tried together at every successive foot* of depth.

The Mid-Channel Line was always chosen for such experiments, because the unavoidable deviations from the intended line are of least importance in mid-channel.

The order of observation chosen was such that the Instruments to be compared (*i. e.*, at same depth of immersion) rapidly succeeded each other, so that they might pass over the Standard Run under as nearly as possible similar external conditions (of wind, gauge depth): the usual order was—

In Series 10, 11, 12.

Three Surface-floats:—
One 1′ "Ball", one 1′ "Rod"; three times in succession.
One 2′ Ball, one 2′ Rod; three times in succession,
and so on down to the full depth.

In Series 14,

One 1′ "Ball", one 1′ "Twin Ball" (with its float); three times in succession.

One 2′ Ball, one 2′ "Twin Ball" (with its float); three times in succession, and so on down to the full depth:

Lastly, 6 "Rods" (of full depth of immersion).

The mean of three observations with one Instrument at any one depth is considered to be a VELOCITY-MEASUREMENT freed from mere observation-errors.

The Result of three observations at every foot of depth in succession down to the full depth, will be called a SET of Subsurface Velocity-Measurements.

At the end of each SET, the Observers changed places, so as to execute pairs of "Sets" by combining which their "personal equations" might be eliminated.

The above arrangements were adopted for the reasons explained in Art. 28*a*, *b*, *c*, and 55.

The SETS are arranged into SERIES for intercomparison and combination *according to the variation of gauge-depth*: those Experiments only being considered comparable in which the Gauge-depth is nearly the same.

[The discussion of the comparative Experiments is deferred to Art. 65.]

57. Mid-channel Subsurface-Velocity variation.—The Series of Subsurface-velocity measurements at every foot of depth—explained in Art. 56, afford the means of investigating this. Five Series, Nos. 10 B.—14 B. executed with the "Single Ball"; and one Series, No. 14 B B. with the "Twin Ball", are available for this purpose.

Reduction of observations.—This was done in a manner quite similar to that described in Art. 29, (for Surface-velocities), Vertical Velocity-curves (Art. 9), being drawn—on a Base line representing a vertical line in mid-channel—for every SET of velocity-measurements, and each day's work on a common base line.

The irregularity of the individual Curves was found to be quite as great as that of the Horizontal Velocity Curves described in Art. 29, and it seemed at first hopeless to disentangle any simple law from such variable data.

[This great variability will be recognized as the necessary consequence of the fluid Motion being *Unsteady*, as explained in Art. 25].

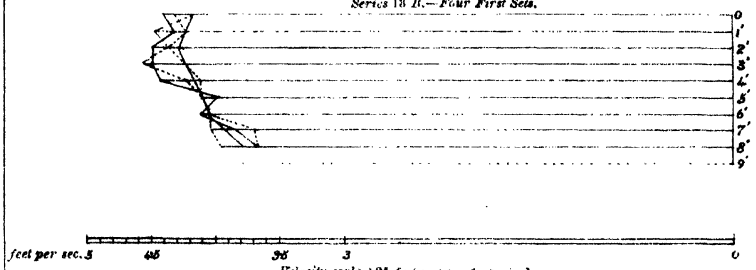
A few only of the Curves are herewith published (at top of *Plate* VII.) to exhibit this.

HYDRAULIC EXPERIMENTS AT ROORKEE.

MID-CHANNEL VERTICAL VELOCITY CURVES.

(Showing Unsteady Motion).

Series 13 B.—Four First Sets.



Velocity-scale, 1·25 feet per sec. to an inch.

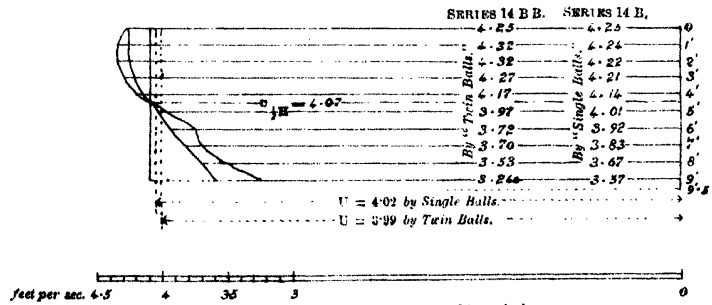
COMPARISON OF INSTRUMENTS.

MID-CHANNEL VERTICAL VELOCITY MEAN CURVE

at Centre-section of Solání Aqueduct

by 'Single Balls' and 'Twin Balls'.

[The "Single Balls" give the flatter Curve].



Velocity-scale, 1·25 feet per second to an inch.

Ordinates (clear lines), indicate Velocities at every foot of depth.

Mid-depth velocity = $v_{\frac{1}{2}H}$ — a chain dotted line.

Mean velocity = U — a dotted line.

Depths below the surface are figured on extreme right.

Scale for depths, 10 feet to an inch.

58. Central vertical plane Discharge.—After some time it seemed probable that the curves—though disagreeing greatly in detail—interlaced (*see Fig.* at top of *Plate* VII.), in such a manner as to be of tolerably constant area. To test this point the area of each separate curve from the surface *down to the lowest depth* of velocity-measurement—was calculated as accurately as possible.

[It is clear that in this way the Area of the segment of the Velocity-curve between the deepest line of measurement and the bottom *is omitted*, so that the areas (and therefore also the Discharges which they represent) are not complete.

To have included this omitted segment, it would have been necessary to make some *hypothesis* as to the magnitude of the bottom velocity. The Experiments as far as they have gone—hardly give sufficient data for this, so that it has been thought advisable to omit this segment, rather than include a doubtful value of it. This will be discussed in Art. 63].

The Results are exhibited in Tables V.—IX., of which the following is an Abstract of Contents:—

Table	Serial No.	Number of "Sets" in each Series.	Number of points of observation	Gauge-depth	Instrument	Locality		Experimental Section	Line of motion	Remarks
V.	10 B.	4	5	5'·90—5'·95	Single Ball	Solání Aqueduct.	Left Chamber	Centre Cross-section.	Mid-channel.	*N. B.*—Every velocity-measurement is the mean of 3 observations.
	11 B.	12	6	7'·25	„		Left Chamber			
VI.	12 B.	20	7	7'·55—7'·65	„		Right Chamber			
VII.	13 B.	22	8	8'·95—9'	„		Left Chamber			
VIII.	14 B.	20	9	9'·25—9'·50	„		Left Chamber			
IX.	14 BB.	20	9	9'·25—9'·50	Twin Balls		Left Chamber			

Col. 3 of the Tables exhibits the Details of Velocity-measurements at the surface, and at every foot of depth.

Each horizontal line exhibits a complete SET of ordinates of one Vertical Velocity-Curve.

Col. 4 exhibits the Areas of the individual Velocity-curves, which of course represent the (superficial) Discharge past a mid-channel vertical line (in square feet per second).

It will be seen that much as the Details of each Curve—compare the

TABLE V.

SUBSURFACE-VELOCITIES AND DISCHARGES.

SOLANI AQUEDUCT, LEFT CHAMBER—CENTRAL VERTICAL PLANE.

[Instrument.—Subsurface Single, 3″ Ball].

Serial No.	1 Date 1875.	2 Gauge-depth.	3 SUBSURFACE VELOCITIES. [Each Velocity is the mean of three observations]. Depths (*d*). 0	1	2	3	4	5	6	7	8	9	4 DISCHARGE through depth (*d*) in sq. feet per sec.	5 WIND. D	V	6 Timekeeper's initials.	7 DISCHARGE through depth (*d*) (pers. equ. eliminated).	8 Diff. from Mean.	9 MEAN VELOCITY, U	10 Mid-depth Velocity. $v_{\frac{1}{2}H}$
SERIES 10 B.	18·2	5·95	3·45	3·49	3·45	3·29	3·26	3·22	..	..	..	..	16·82	S	8	W	16·89	− ·05	3·38	3·42
	„	5·90	3·45	3·49	3·45	3·49	3·19	3·09	..	..	..	..	16·96	S	15	R				
	„	„	3·45	3·49	3·57	3·37	3·12	2·97	..	..	..	..	16·77	S	15	W	16·98	+ ·04	3·40	3·50
	„	„	3·52	3·70	3 66	3·40	3·09	3·09	..	..	..	..	17·20	S	16	R				
	a Means, ..		3·47	3·54	3·53	3·39	3·16	3·09	..	..	..	..	16·94	..	..		16·94	..	3·39	3·46
	b By formulæ, ...		*3·46*	*3 56*	*3 52*	*3·37*	*3·07*	*2·68*	..	..	..	..	*16·66*	*See* Art. **60**, formulæ (24), (26).						
	c Discrepancy, ..		+ ·01	− ·02	+ ·01	+ ·02	+ ·09	+ ·41	..	..	..	..	+ ·28							
	D Discharge		..	3·51	7·06	10·53	13·80	16·94	..	..	..	..		*See* Art. **72**.						
	A Mean Velocity,		3·47	3·51	3·53	3·51	3·45	3·39	..	..	..	..		Carried on to Table X.						
SERIES 11 B.	19·2	7·25	3·85	3·95	4·00	3·80	3 61	3·37	3·40	..	..	..	22·28		0	W	22·08	− ·01	3·68	3·61
	„	„	3·90	3·80	3·95	3·61	3·66	3·45	3·49	..	..	..	21·87	S	8	R				
	„	„	3·70	3·75	3·85	3 66	3·53	3·33	3·26	..	..	..	21·51	S	7	W	21·87	− ·32	3·65	3·76
	„	„	3·66	4·00	4·05	3·85	3·53	3·29	3·33	..	..	..	22 24	S	7	R				
	„	„	3·80	3·90	3·90	3·70	3·61	3·40	3·19	..	..	..	21·96	S	7	W	22·24	+ ·05	3·71	3·83
	„	„	3·70	3·80	3·75	3·95	3·53	3·61	3·33	..	..	..	22·52	S	9	R				
	29·2	7·25	4·00	3·85	3·80	3·80	3·57	3 66	3·45	..	..	..	22·55		0	W	22·35	+ ·16	3·72	3·78
	„	„	3·85	3·95	3·95	3·75	3·57	3·37	3·37	..	..	..	22·15	S	5	R				
	„	„	3·75	3·85	3·90	3·70	3·85	3·57	3·49	..	..	..	22·29	S	5	W	22·54	+ ·35	3·76	3·75
	„	„	3·90	4·00	3·85	3·80	3·66	3·66	3·49	..	..	..	22·80		0	R				
	„	„	3·80	3·80	3·80	3·66	3·49	3·33	3·45	..	..	..	21·65	S	7	W	22·04	+ ·15	3·67	3·68
	„	„	3·90	3·90	3·90	3·70	3·61	3·66	3·37	..	..	..	22·43		0	R				
	a Means, ...		3·82	3·88	3·89	3·75	3·60	3·47	3·38	..	..	..	22·19	..	..		22·19		3·70	3.75
	b By formulæ, ...		The means of observation are too irregular to admit of comparison with formulæ.																	
	c Discrepancy, ...																			
	D Discharge		..	3·85	7·74	11·58	15·24	18·80	22·20	..	..	..		*See* Art. **72**.						
	A Mean Velocity		3 82	3·85	3 87	3·86	3·81	3·76	3·70	..	..	..		Carried on to Table X.						

TABLE VI.

SUBSURFACE-VELOCITIES AND DISCHARGES.

SOLANI AQUEDUCT, RIGHT CHAMBER—CENTRAL VERTICAL PLANE.

[*Instrument.—Subsurface Single, 3″ Ball*].

Serial No.	1	2	3										4	5	6	7	8	9	10	11
			SUBSURFACE VELOCITIES. [Each Velocity is the mean of three observations].																	
			Depths (d).																	
	Date 1875.	Gauge-depth.	0	1	2	3	4	5	6	7	8	9	DISCHARGE through 7′ depth in sq. feet per sec.	WIND. D V	Timekeeper's initial.	DISCHARGE through 7′ depth (peral. eqn. eliminated).	Dif. from Mean.	∁ MEAN VELOCITY.	Mid-depth Velocity, $v_{\frac{1}{2}H}$	Dif. $(v_{\frac{1}{2}H} - \overline{v})$.
SERIES 12 B.	22·2	7·65	4·00	3·90	3·66	3·90	3·53	3·66	3·53	3·33	..	..	24·76	V 15	W	25·77	+·01	3·68	3·85	+·17
	„	„	4·05	3·85	4·00	4·05	3·90	3·61	3·70	3·29	..	..	26·77	N E 20	R					
	23·2	7·55	3·80	3·95	3·85	3·75	3·61	3·61	3·49	2·97	..	..	25·76	..	W	25·84	+·08	3·69	3·75	+·06
	„	„	3·75	3·85	3·80	3·95	3·70	3·53	3·53	3·12	..	..	25·92	..	R					
	„	„	3·85	3·85	3·90	3·66	3·45	3·75	3·37	3·09	..	..	25·51	..	W	25·94	+·18	3·71	3·72	+·01
	„	„	3·90	3·95	3·80	4·00	3·75	3·66	3·49	3·30	..	..	26·37	..	R					
	„	„	3·95	3·85	3·80	3·70	3·61	3·70	3·49	3·23	..	..	25·77	..	W	26·06	+·30	3·72	3·68	−·04
	„	„	3·90	4·05	3·95	3·75	3·66	3·75	3·51	3·26	..	..	26·34	..	R					
	24·2	7·55	3·75	3·80	3·95	3·95	3·95	3·53	3·37	3·23	..	..	25·99	..	W	25·90	+·14	3·70	3·85	+·15
	„	7·58	3·66	3·85	3·75	3·70	3·80	3·75	3·45	3·30	..	..	25·81	S E 6	R					
	„	7·60	3·61	3·85	4·00	3·61	3·80	3·45	3·45	3·16	..	..	25·45	S E 7	W	25·61	−·15	3·66	3·73	+·07
	„	„	3·70	3·90	3·75	3·75	3·75	3·70	3·45	3·03	..	..	25·77	S E 6	R					
	„	„	3·70	3·75	3·90	3·70	3·66	3·75	3·45	3·12	..	..	25·63	S E 20	W	25·66	−·10	3·67	3·70	+·03
	„	„	3·70	3·90	3·90	3·90	3·53	3·4	3·53	3·03	..	..	25·68	S E 17	R					
	26·2	7·60	3·85	4·00	3·85	3·80	3·57	3·41	3·66	3·16	..	..	25·92	E 13	W	25·72	−·04	3·68	3·69	+·01
	„	„	3·75	3·75	3·75	3·80	3·57	3·66	3·41	3·23	..	..	25·51	N W 9	R					
	„	„	3·66	3·80	3·75	3·61	3·66	3·49	3·33	3·26	..	..	25·09	W 10	W	25·52	−·29	3·65	3·74	+·09
	„	„	3·80	3·70	3·95	3·90	3·80	3·57	3·57	3·16	..	..	25·94	W 19	R					
	„	„	3·61	3·75	3·85	3·85	3·75	3·41	3·41	3·13	..	..	23·40	$\frac{E}{W}$ $\frac{17}{21}$	W	25·56	−·20	3·65	3·76	+·11
	„	„	3·95	3·85	3·90	3·85	3·57	3·61	3·41	2·97	..	..	25·72	W 19	R					
	a Means, ...		3·80	3·86	3·85	3·81	3·68	3·60	3·48	3·17	..	..	25·76	..	..	25·76	..	3·68	3·75	+·06
	b By formulæ, ...		*3·82*	*3·86*	*3·86*	*3·82*	*3·74*	*3·62*	*3·44*	*3·23*	..	..	*25·89*			*See* Art. **60**, Formulæ (24), (26).				
	c Discrepancy, ...		−·02	..	−·01	−·01	−·06	−·02	+·04	−·06	..	..	−·13							
	D Discharge		..	3·83	7·70	11·52	15·28	18·90	22·50	25·76	..	..	..	*See* Art. **72**.						
	A Mean Velocity,		3·80	3·83	3·85	3·84	3·82	3·78	3·75	3·68	..	..	..	Carried on to Table XI.						

TABLE VII.

SUBSURFACE-VELOCITIES AND DISCHARGES.

SOLANI AQUEDUCT, LEFT CHAMBER—CENTRAL VERTICAL PLANE.

[*Instrument.—Subsurface Single, 3″ Ball*].

SERIES 18 B.

Serial No.	1 Date 1875.	2 Gauge-depth.	3 SUBSURFACE-VELOCITIES. [Each Velocity is the mean of three observations.] Depths (d). 0	1	2	3	4	5	6	7	8	9	4 DISCHARGE through 8′ depth in sq. feet per sec.	5 WIND. D	V	6 Timekeeper's Initial.	7 DISCHARGE through 8′ depth (Serial, sqn. eliminated).	8 Diff. from Mean.	9 MEAN VELOCITY.	10 Mid-depth Velocity. $v_{\frac{1}{2}H}$	11 Diff. $(v_{\frac{1}{2}H} - U)$
	27·1	9·00	4·17	4·22	4·29	4·22	4·17	4·11	4·05	3·90	3·75	..	32·91	..		W	33·07	−·26	4·13	4·14	+·01
	„	„	4·29	4·22	4·35	4·22	4·11	4·11	4·05	4·05	3·95	..	33·22	..		R					
	„	„	4·41	4·29	4·48	4·48	4·41	3·95	4·11	3·85	3·66	..	32·93	..		R	32·59	+·26	4·07	4·32	+·25
	„	„	4·17	4·48	4·35	4·55	4·22	4·11	4·05	3·70	3·66	..	32·25	..		W					
	„	„	4·17	4·48	4·29	4·17	4·22	4·05	3·90	3·85	3·61	..	33·45	..		W	33·46	+·13	4·18	4·29	+·11
	„	„	4·17	4·11	4·29	4·17	4·35	3·90	3·90	3·77	3·70	..	33·48	..		R					
	28·1	8·95	4·29	4·29	4·35	4·29	4·05	4·22	4·17	3·80	3·61	..	33·15	..		W	33·33	·00	4·17	4·20	+·03
	„	„	4·41	4·55	4·41	4·22	4·35	4·11	4·17	3·75	3·75	..	33·51	N	E 4	R					
	„	„	4·69	4·55	4·41	4·17	4·29	4·17	4·11	3·90	3·75	..	33·74	N	E 4	W	33·65	+·32	4·21	4·29	+·08
	„	„	4·48	4·41	4·35	4·29	4·29	4·17	4·00	3·90	3·80	..	33·55	N	E 4	R					
	„	„	4·48	4·29	4·29	4·35	4·22	4·05	4·05	3·95	3·70	..	33·29	N	E 4	W	33·68	+·35	4·21	4·29	+·08
	„	„	4·48	4·22	4·55	4·48	4·35	4·35	4·17	3·85	3·66	..	33·96	S	E 8	R					
	„	„	4·17	4·48	4·35	4·35	4·22	4·35	4·11	3·90	3·66	..	33·84	S	4	W	33·35	+·02	4·17	4·22	+·05
	„	„	4·29	4·17	4·29	4·05	4·22	4·25	4·17	3·85	3·61	..	32·85	..		R					
	29·1	8·95	4·35	4·48	4·48	4·35	4·29	4·17	4·05	3·85	3·75	..	33·71	..		W	33·58	+·25	4·20	4·39	+·19
	„	„	4·48	4·11	4·35	4·35	4·48	4·22	4·05	3·90	3·80	..	33·45	E	10	R					
	„	„	4·29	4·35	4·41	4·35	4·29	4·11	3·95	3·85	3·57	..	33·27	E	10	W	33·20	−·13	4·15	4·29	+·14
	„	„	4·55	4·29	4·11	4·41	4·29	4·17	3·95	3·75	3·66	..	33·13	..		R					
	„	„	4·35	4·48	4·29	4·22	4·11	4·29	4·17	4·05	3·75	..	33·80	..		W	33·59	+·26	4·20	4·14	−·06
	„	„	4·11	4·29	4·35	4·55	4·17	4·05	4·22	3·80	3·80	..	33·38	N	E 6	R					
	„	„	4·35	4·48	4·29	4·35	4·41	4·29	3·85	4·05	3·85	..	33·99	N	E 6	W	33·27	−·06	4·16	4·32	+·16
	„	„	4·29	4·11	4·35	4·22	4·22	4·11	4·08	3·66	3·66	..	32·55	..		R					
	a Means, ...		4·34	4·33	4·35	4·31	4·26	4·15	4·06	3·86	3·71	..	33·33	..		..	33·33	..	4·17	4·26	+·09
	b By formulæ, ...		*4·34*	*4·35*	*4·34*	*4·30*	*4·24*	*4·15*	*4·03*	*3·89*	*3·73*	..	*33·35*	*See* Art. 60, Formulæ (24), (26).							
	c Discrepancy, ...		0	−·02	+·01	+·01	+·02	0	+·03	−·03	−·02	..	−·02								

TABLE VIII.

SUBSURFACE-VELOCITIES AND DISCHARGES.

SOLANI AQUEDUCT, LEFT CHAMBER—CENTRAL VERTICAL PLANE.

[*Instrument.—Subsurface Single 3″ Ball*].

Serial No.	1 Date 1875.	2 Gauge-depth.	3 SUBSURFACE VELOCITIES. [Each Velocity is the mean of three observations]. Depths. 0	1	2	3	4	5	6	7	8	9	4 DISCHARGE through 9′ depth in sq. feet per sec.	5 WIND. D	V	6 Timekeeper's Initial.	7 DISCHARGE through 9′ depth (parel. sqn. eliminated).	8 Diff. from Mean.	9 MEAN VELOCITY.	10 Mid-depth Velocity. $v_{\frac{1}{2}H}$	11 Diff. $(v_{\frac{1}{2}H} - V)$
SERIES 14 B.	5·4	9·50	4·33	4·29	4·41	4·05	4·17	4·29	3·80	3·75	3·85	3·75	36·77	..		R	36·30	+·16	4·03	4·16	+·13
	„	„	4·10	4·22	4·41	4·32	4·20	3·97	3·95	3·59	3·45	3·39	35·83	S b W	8	W					
	6·4	9·50	4·26	4·11	4·05	4·29	4 05	4·11	3·90	3·75	3·80	3·66	35·97	..		R	35·93	−·21	3·99	4·07	+·08
	„	„	4·32	4·17	4·29	4·14	4·14	3·97	4·03	3·73	3·49	3·66	35·88	..		W					
	„	„	4·36	4·17	4·29	4·11	4·05	4·17	3·70	3·80	3·61	3·53	35·92	..		R	35·74	−·40	3·97	4·01	+·04
	7·4	9·50	4·28	4·26	4·11	4·11	4·03	3·80	3·95	3 77	3·73	3·33	35·56	..		W					
	„	„	4·19	4·00	4·17	4·00	4·00	4·05	3·95	4·11	3·66	3·61	35·88	..		R	36·14	·00	4·02	3·98	−·04
	„	„	4·19	4·41	4·32	4·32	4·00	3·87	4·00	3·66	3·95	3·57	36·39	..		W					
	8·4	9·50	4·30	4·22	4·11	4·22	4·35	3·90	3·95	3·95	3·75	3·33	36·30	S W	3	R	36·63	+·49	4·07	4·16	+·09
	„	„	4·18	4·20	4·44	4·44	4·32	4·05	4.00	3·75	3·90	3·51	36·96	V	30	W					
	9·4	9·50	4·23	4·11	4·41	4·35	4·22	3·95	3·80	3·66	3·41	3·57	35·77	..		R	36·03	−·11	4·00	4·05	+·05
	„	„	4·33	4·38	4·03	4·20	4·00	4·03	4·14	3·87	3·73	3·64	36·29	..		W					
	10·4	9·50	4·32	4·17	4·11	4·22	3·95	4·00	3·75	4·00	3·61	3.41	35·70	..		R	36·24	+·10	4·03	4·10	+·07
	„	„	4·32	4·35	4·41	4·22	4·29	4·17	3·70	3·80	3·66	3·75	36 73	..		W					
	12·4	9·40	4·08	4·41	4·11	4·29	4·22	3·90	3·85	3·80	3·57	3·26	35·87	..		R	35·89	−·25	3·99	4·07	+·08
	„	„	4·17	4·26	4·11	4·05	4·17	3·97	4·05	3·80	3·61	3·64	35·91	..		W					
	14·4	9·40	4·18	4·17	3·95	4·29	4·29	4·22	4·00	4·00	3·85	3·80	36·75	..		R	36·27	+·13	4·03	4·10	+·07
	„	„	4·29	4·32	4·20	4·03	3·90	3·97	3·90	3·83	3·68	3·59	35·79	..		W					
	15·4	9·25	4·28	4·05	4·35	4·17	4·17	3·90	3·95	4·05	3·49	3·66	36·08	..		R	36·25	+·11	4·03	4·03	..
	„	„	4·25	4·44	4·17	4·44	4·20	3·83	3·95	3·85	3·64	3·66	36·41	..		W					
	a Means,		4·25	4·24	4·22	4·21	4·14	4·01	3·92	3·83	3·67	3·57	36·14	..		..	36·14	..	4·02	4·07	+·05
	b By formulæ,		*4·25*	*4·24*	*4·21*	*4·17*	*4·11*	*4·03*	*3·93*	*3·81*	*3·68*	*3·53*	*36·09*	*See* Art. 60, Formulæ (24), (26).							
	c Discrepancy,		..	..	+·01	+·04	+·03	−·02	−·01	+·02	−·01	+·04	+·05								

TABLE IX.

SUBSURFACE-VELOCITIES AND DISCHARGES.

SOLANI AQUEDUCT, LEFT CHAMBER—CENTRAL VERTICAL PLANE.

[*Instrument.—Subsurface "Twin 3" Balls."*]

Serial No.	1 Date 1875.	2 Gauge-depth.	3 Subsurface-Velocities. [Each Velocity is the mean of three observations.] Depths. 0	1	2	3	4	5	6	7	8	9	4 Discharge through 9′ depth in sq. feet per sec.	5 Wind. D	V	6 Timekeeper's Initial.	7 Discharge through 9′ depth (serial eqn. eliminated).	8 Diff. from Mean.	9 By "Twin Balls" (Series 14 B B).	9A By "Single Balls" (Series 14 B)(from Table VIII.).	10 Mid-depth Velocity. $v_{\frac{1}{2}H}$	11 Diff. $(v_{\frac{1}{2}H} - V)$.
SERIES 14 B B.	5·4	9·50	4·33	3·74	3·72	3·98	4·54	3·80	3·57	3·11	3·47	3·27	33·57	..		R	34·73	— 1·22	3·86	4·03	4·08	+ ·12
	„	„	4·10	4·44	4·48	4·44	4·38	3·61	3·70	3·73	3·57	2·66	35·88	S*b* W	8	W						
	6·4	9·50	4·26	4·27	4·61	4·02	4·47	3·62	3·73	3 29	3·45	3·18	35·28	..		R	36·34	+ ·39	4·04	3·99	4·06	+ ·02
	„	„	4·32	4·20	3·99	4·06	4·12	4·02	3·99	3·60	3·08	3·59	37·39	..		W						
	„	„	4·36	3·49	4·17	4·60	4·05	3·55	3·51	3·59	3·51	3·49	34·18	..		R	34·87	— 1·08	3·87	3·97	4·03	+ ·16
	7·4	9·50	4·28	4·02	4·30	4·11	4·06	4·44	3·60	3·48	3·65	3·28	35·56	..		W						
	„	„	4·19	4·53	4·47	4·05	4·27	3·93	3·87	4·17	4·00	3·19	37·25	..		R	36·65	+ ·70	4·07	4·02	4·10	+ ·03
	„	„	4·19	4·41	4·08	4·50	4·17	4·03	3·75	3·65	3·79	3·06	36·05	..		W						
	8·4	9·50	4·30	4 23	4·53	4·65	3·59	4·29	3·32	3 81	3·87	2·99	36·07	S W	3	R	36·42	+ ·47	4·05	4·07	4·02	— ·03
	„	„	4·18	4·79	4·23	4·23	4·15	4 06	3·68	4·05	3·65	3·24	36·76	V	30	W						
	9·4	9·50	4·23	4·05	3·99	4·69	4·27	3·78	4·00	4·12	3·41	3·69	36·06	..		R	36·42	+ ·47	4·05	4·00	4·18	+ ·13
	„	„	4·33	4·56	4·41	4·32	4 26	4·42	3·99	3·84	3·14	3·22	36 77	..		W						
	10·4	9·50	4·32	4·67	4·27	4·29	4·17	4·36	3·41	4·15	3·15	3·76	36·67	..		R	36·02	+ ·07	4·00	4·03	4·10	+ ·10
	„	„	4·32	4·41	4·62	4·32	4·33	3·55	3·87	3·36	3·28	2·96	35·37	..		W						
	12·4	9·40	4·08	4·39	4·27	4·09	3·83	4·27	3·63	3·48	3·55	2·45	35·00	..		R	34·89	— 1·06	3·88	3·99	4·06	+ ·18
	„	„	4·17	4·25	4·44	3·84	4·30	3·83	3·35	3·73	3·14	3·11	34·77	..		W						
	14·4	9·40	4·18	4·37	4·41	4·29	3·93	4·05	3·71	4·00	3·75	3·49	36·45	..		R	36·74	+ ·79	4·08	4·03	4·01	— ·07
	„	„	4·29	4·59	4·60	4·47	4·14	3·90	3·90	3·77	3·74	3·46	37·02	..		W						
	15·4	9·25	4·28	4·55	4·36	4·33	4·17	3·75	3·78	3·61	3·61	3·60	36·09	..		R	36·40	+ ·45	4·05	4·03	4·05	+ ·00
	„	„	4·25	4·53	4·54	4·17	4·20	4·06	4·11	3·52	3·79	3·16	36·71	..		W						
	a Means, ...		4·25	4·32	4·32	4·27	4·17	3·97	3·72	3·70	3·53	3·24	35·95	..		..	35·95	..	3·99	4·02	4·07	+ ·08
	b By formulæ, ...		*4·26*	*4·32*	*4·33*	*4·30*	*4·22*	*4·10*	*3·94*	*3·73*	*3·48*	*3·19*	*36·58*	*See* Art. **60**, Formulæ (24), (26).								
	c Discrepancy, ...		— ·01	..	— ·01	— ·03	— ·05	— ·13	— ·22	— ·03	+ ·05	+ ·05	— ·63									
	A Means by "Single Ball," ...		4·25	4·24	4·22	4·21	4·14	4·01	3·92	3·83	3·67	3·57	36·14	From Table VIII., Series 14 B.								
	d Discrepancy, ...		..	+ ·08	+ ·10	+ ·06	+ ·03	— ·04	— ·20	— ·13	— ·14	— ·33	— ·19									

figures in *any one* vertical column under Col. 3)—differ, the Areas (Col. 4) are *tolerably constant*, and that the discrepancies are mostly due to the Observers' 'personal equation'.

Col. 7 shows the Results (Areas) of Col. 4 combined by pairs so as to eliminate the 'personal equation' of the Observers—(the Time-keeper's initial is shown in Col. 6). These Results are *much more approximately constant:* the discrepancies from the mean value—shown in Col. 8 are all *very small quantities*, considering the variable state of external conditions (principally wind)—the largest being only

·35 out of 22·54, or $\frac{1}{64}$th part of whole in Experiments with "Single Balls",
1·22 out of 33·73, or $\frac{1}{28}$th part of whole in Experiments with "Twin Balls".
This can only be due to one or other of two causes—

1°. The Total (superficial) Discharge through the mid-channel vertical plane is approximately constant under similar external conditions, though its distribution varies greatly from instant to instant, ... } ...(21).

2°. Or else—the velocity-measurements in each stream line being effected (not simultaneously but) in succession, it is probable that each is done *at a different phase of its variation;* in which case it is possible that the Total Discharge as calculated from velocity-measurements at each foot of depth *in different phases of their variation* may be nearly the same (on the whole) *as if each velocity-measurement had been a measurement at its own mean phase,*..... } ...(22).

It is interesting to compare these Results with the similar conclusions (Results 8, 9, Art. 30) as to Constancy of Surface-Discharge.

These Results as to probability of Constancy of Discharge (across Surface and in a mid-channel vertical plane) would be of very great importance in Theory of fluid motion if they could be certainly established: but it is at present unfortunately impossible to detect which explanation 1° or 2° is the true one without the means of making all the observations *really simultaneous*, an apparent impossibility.

[It would be equally important to extend these Experiments to other vertical planes besides the mid-channel one: but this could not be done in one season].

59. *Geometrical Illustration.*—A good idea of the variation of velocity at a point from instant to instant in such a manner as to preserve—

(*a*). Constant (cubic) Discharge through the whole cross-section,
(*b*). Constant (superficial) Discharge in horizontal planes,
(*c*). Constant (superficial) Discharge in vertical planes,

is to imagine the curved surface of the "Velocity-surface" (Art. 9) to consist of some thin *flexible* membrane filled with incompressible fluid (such as water), whilst the plane Base is rigid.

The *form* of the Surface might then be altered freely, so that the ordinates (which represent velocities) would vary, but the Volume (representing the cubic Discharge) would remain constant: such a condition would represent Case (*a*).

Next, imagine the curved contour of each Horizontal and Vertical Velocity-curve to consist of a thin flexible cord, and the area filled with incompressible fluid, the Base line being a rigid line.

The *form* of each such Curve might then be altered freely, so that the ordinates (which represent velocity) would vary, but the Area (representing the Superficial Discharge) would remain constant: such a condition would represent Cases (*b*) and (*c*)

60. Mid-channel Vertical Velocity Mean Curve.—The individual Velocity-curves have been explained to be of very irregular shape, and disagreeing in detail; the MEAN CURVE resulting from combining a great many Velocity-curves (under similar external conditions) will be found however strikingly regular—*see Plate* VIII.

This points to the conclusion (Result 5 of Art. 26), that

"The 'mean-velocity' at a point—taken through a considerable interval of time—is constant in magnitude under the same external conditions,.....

This granted, it follows that the MEAN CURVE is of invariable form under the same external conditions at the same cross-section, and that therefore the Mean Velocity at any depth is a function *solely of the depth*, so that

If u = "mean velocity" at a depth z,

$$u = f(z), \qquad (23).$$

[This question is experimentally investigated in the Mississippi Report, in the Darcy-Bazin Report, and in the Révy Report. In the two former, the conclusion was, that the curve is approximately a common parabola: in the Révy Report it is said to be a straight line.

In the Mississippi Report the position of the axis of the parabola is shown to depend on the direction and force of the wind, it being at about ·3 of the depth in calm weather.]

Of the 6 Mean Curves figured in *Plate* VIII., as being the Curves representing the Means of the 6 Series, Nos. 10 B. to 14 B., and 14 BB., the second (that of Series 11 B.) is too irregular from some cause unknown to be of any use in this question.

The remaining 5 figures will be found to be all more or less approximately common parabolæ, the depth of immersion of axis and parameter being however different in each, thus—

If V = maximum velocity,

Z = depth below surface of line of maximum velocity,

v = velocity at any depth z below surface,

p = parameter of parabola,

then the general equation of the parabola is,

$$(z - Z)^2 = p\,(V - v), \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (24).$$

A probable value of Z can generally be found by inspection; the value of V must be chosen such as is likely to suit the observed velocities in the neighbourhood of the depth Z, after which several values of p can be calculated from the other data—the most favorable for this purpose being the known velocities (v) *near the full depth* (H).

The values of V, Z, p which nearly suit the 5 Mean Curves—are shown in following Table:—

Table	Serial No.	Number of "Sets" in "Series"	Number of points of observation	Instrument	General Direction of wind	Mean Gauge-Depth	Assumed Max. Velocity, V	Depth of Max. Velocity, Z	Parameter of Parabola, p
V.	10 B.	4	5	"Single Ball"	S	5'·9	3·56	1'·25	16
V.	11 B.	12	6	"	S	7'·25	Too irregular to be worth computing.		
VI.	12 B.	20	7	"	S	7'·6	3·87	1'·5	47
VII.	13 B.	22	8	"	V	8'·95	4·35	1'	79
VIII.	14 B.	20	9	"	0	9'·45	4·25	0	112
IX.	14 BB.	20	9	"Twin Balls"	0	9'·45	4·33	1'·75	46

The three lines, marked (a), (b), (c), under each of the "Series" in Tables V. to IX. exhibit

(a), the Mean "velocity" at each foot of depth by observation,
(b), the calculated values of the same by formula (24).
(c), the discrepancies between (a), (b).

All these Results (a, b, c,) are also well exhibited by the figures in Plate VIII., in which

(a), the Mean Curve of observation is shown by a clear line,
(b), the Parabola (24) is shown by a dotted line.

It will be at once seen that the discrepancies are mostly very small quantities, and that therefore it may be concluded with tolerable certainty, especially as this Result agrees with both the Mississippi and French Results,

In a symmetric section the central Vertical Velocity-Curve is approximately a parabola to within a short distance of the bottom, ... } (25).

[This Result disagrees with that of the Révy Report, which is, that the Vertical Velocity-Curve is a straight line, but the fact is that this Result is really dependent on only one or two Series of experiments (page 41 of Révy Report) on the La Plata, a *tidal estuary of the sea*, and can therefore only be looked on as a *particular result*, not as a *general law* of fluid motion.

The mass of experimental evidence that this curve is approximately a parabola is really now very great, and it may be looked on as one of the best established facts of modern Hydraulic Science].

The Area of the Curve down to any desired depth (H)—which of course represents the (superficial) Discharge down to that depth—is easily found by the well known property of the parabola, (Area = two-thirds of circumscribing rectangle).

Thus if, in addition to previous notation,

v_o = surface-velocity,

v_H = velocity at the desired depth (H),

$$\left.\begin{matrix}\text{Then Discharge}\\ \text{or Area}\end{matrix}\right\} = VH - \tfrac{1}{3}\left\{(V - v_o).Z + (V - v_H)(H - z)\right\} \quad (26).$$

If the velocity at the depth H have not been measured, it can of course is be calculated from the equation (24) of the Curve.

If the surface velocity (v_o), mid-depth velocity ($v_{\frac{1}{2}H}$), and full-depth velocity (v_H) have been all measured, the Area, or (superficial) Discharge still more easily found by Simson's well known Rule, thus—

$$\left.\begin{matrix}\text{Discharge}\\ \text{or Area}\end{matrix}\right\} = \frac{H}{6}.(v_o + 4\,v_{\frac{1}{2}H} + v_H) \ldots\ldots\ldots\ldots (26A).$$

61. Axis and parameter.—The number of comparable Curves in the above Table is too few—being only four, viz., those of Series 10 B., 12 B., 13 B., 14 B.,—for any proper investigation of the law of variation of the position of the axis and of magnitude of parameter (p).

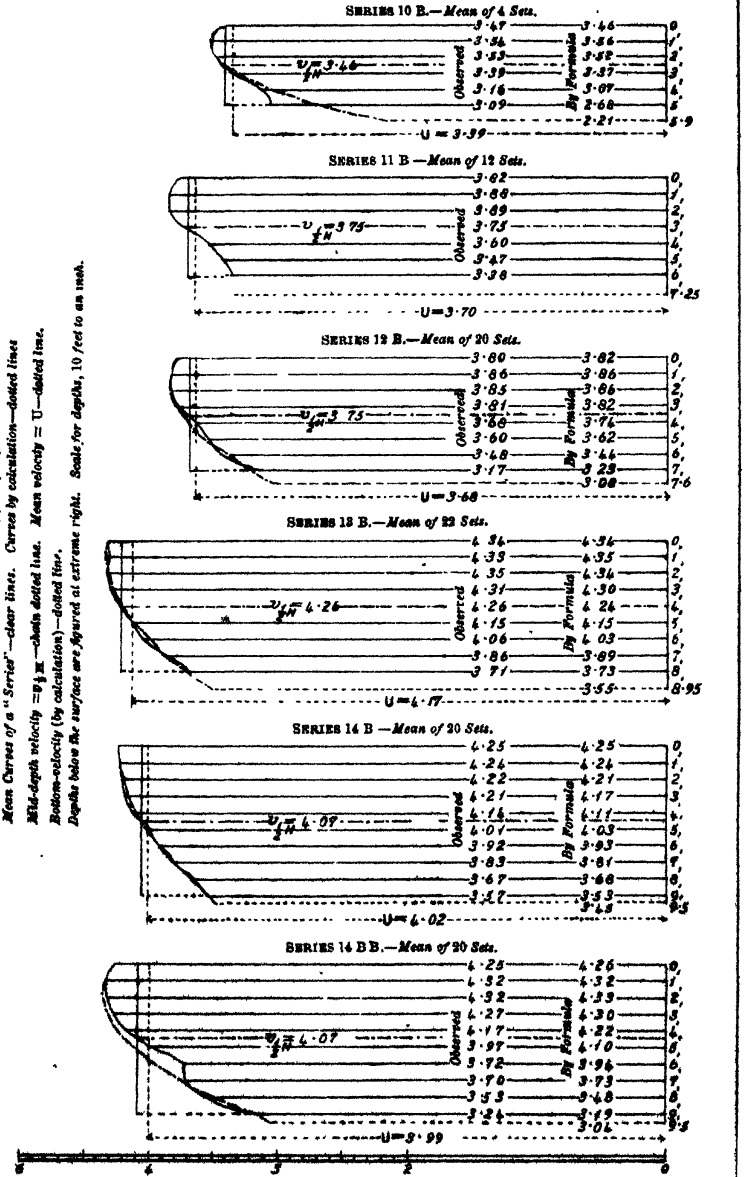
[Series 14 BB., with a different Instrument is of course incomparable].

HYDRAULIC EXPERIMENTS AT ROORKEE.

MID-CHANNEL VERTICAL VELOCITY MEAN CURVES

at Centre-section of Soldni Aqueduct.

Ordinates (clear lines) indicate Velocities at every foot of depth.
Mean Curves of a "Series"—clear lines. Curves by calculation—dotted lines
Mid-depth velocity $= v_{\frac{1}{2}H}$—chain dotted line. Mean velocity $= U$—dotted line.
Bottom-velocity (by calculation)—dotted line.
Depths below the surface are figured at extreme right. Scale for depths, 10 feet to an inch.



Such partial deductions as can fairly be drawn, bear out to a certain extent the conclusions on the same points in the Mississippi and Darcy-Bazin Reports.

Thus it will be seen from the above Table, that the depth of axis (Z) seems to depend *on the direction of the wind*, being increased by an up-stream wind, (so far confirming the conclusion of the Mississippi Report) —but being *in no one case nearly so deep-seated* as stated in the Mississippi Report.

There are not enough data however to determine the law of variation of position of the axis.

The magnitude of the parameter (p) will be found to be nearly given by following formula,—where H = full depth,

$$p = 13{\cdot}5\ \mathrm{H}^4, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (27).$$

[Much confidence cannot of course be placed in this Result† depending on only four curves: the Results of the American and French Experiments are—

Mississippi Report, *see* Eq. (2) at top of page 252, $p = \dfrac{\mathrm{H}^3}{\sqrt{\cdot 1856\,\mathrm{U}}}$ ...(27*a*).

where U = mean velocity of cross-section.

Darcy-Bazin Report, (*see* page 228), $p = \dfrac{\mathrm{H}^{\frac{3}{2}}}{24\sqrt{i}}$ ..... (27*b*).

where i = slope of water-surface.

Not one of the three formulæ (27, 27*a*, 27*b*,) agree *apparently* even in *form* with one another, beyond a general sort of agreement that p increases very rapidly with H, (as $\mathrm{H}^{\frac{3}{2}}$, H^3 or H^4).

The fact is, not one of the three really rests on a sufficient number of experiments to be considered well established.

On page 243 of the Mississippi Report, it is stated, that the "curves of observation are not sufficient for the deduction of a law"; and from page 247, it appears that, after all, this Result (27*a*) depends *principally* upon the comparison of only 4 "mean curves".

The French Experiments, on which Result (27*b*) is based, comprise only 8 Series in channels *not exceeding* 1·23 *deep*. The Report of the Commission of the French Academy of Sciences, (page xxvii), is unfavorable to the acceptance of this Result.

However, all three (the Mississippi, the French, and the present Experiments) agree in the fact that the parameter (p) increases very rapidly with the depth (H).

M. Dupuit shows* that on a certain hypothesis as to law of fluid friction, viz., that it $\propto \dfrac{du}{dx}$ or $\dfrac{du}{dy}$, the parameter would be *constant with same slope* (i).

* Études Théoriques et Pratiques sur le mouvement des eaux, 2nd Ed. Art. 16.

† especially as the effect of Wind is not eliminated.

The Experimental Results appear to contradict this: it appears to the Author, however, that this Result of M. Dupuit's is perhaps reconcilable with the Experimental Results: the fact is, that in theoretical investigations, the term "the slope" (i) usually means the "longitudinal slope of the water-surface", a quantity exceedingly difficult to measure on any but very small channels, and moreover so small in natural channels that a small error in its estimation becomes of great importance.

Thus—in the present Experiments—although the observations yielding the Vertical Velocity Mean Curves of *Plate* VIII. were all executed at the same place on the centre cross-section of the Solání Aqueduct, so that the *slope of the Bed* is presumably the same throughout the observations, still it does not therefore follow that the quantity denoted by i in M. Dupuit's formulæ—*i. e.*, the slope of the stream-lines was therefore also constant thoughout the Experiments, especially if the Canal be rising or falling at the time.

No attempt was made to estimate this slope; indeed there is probably no way yet known of measuring it with sufficient accuracy. The difficulty—nay almost impossibility—of doing this is well explained in the Révy Report; in fact, the *surface-velocity itself* is there proposed as the most delicate measure of the inclination of water sureface.

62. Mid-channel Mid-depth and Mean Velocities.—It has been shown that on the parabolic theory,

$$\left.\begin{matrix}\text{Discharge through central}\\ \text{vertical plane,}\end{matrix}\right\} = \frac{H}{6}\left(v_o + 4\,v_{\frac{1}{2}H} + v_H\right) \ldots\ldots (28).$$

Now, if U = MEAN VELOCITY through central vertical plane, then, by the definition of "mean velocity", it is clear that

$$UH = \text{Discharge} = \frac{H}{6}\left(v_o + 4\,v_{\frac{1}{2}H} + v_H\right)$$

$$\therefore U = \tfrac{1}{6}\left(v_o + 4\,v_{\frac{1}{2}H} + v_H\right) \ldots\ldots\ldots\ldots (29).$$

$$= v_{\frac{1}{2}H} + \tfrac{1}{3}\left(\frac{v_o + v_H}{2} - v_{\frac{1}{2}H}\right)$$

Now, $v_{\frac{1}{2}H}$ lies between v_o, v and cannot differ *greatly* from their arithmetic mean, hence it follows that

$$U = v_{\frac{1}{2}H} \text{ approximately} \ldots\ldots\ldots\ldots (30).$$

$$\left.\begin{matrix}\text{or the "Mid-depth" and "Mean velocities" are approximately the same}\\ \text{in the central vertical plane,} \ldots\ldots\ldots\ldots\end{matrix}\right\} (30A).$$

The following Table shows the values of U, and $v_{\frac{1}{2}H}$ by experiment taken from line (a) of each of the Tables V., VI., VII., VIII., IX., the MEANS only of each SERIES being here shown.

Table	Serial No.	Number of "Sets" in Series	Number of points of observation	Gauge-depth	MID-DEPTH VELOCITY $v_{\frac{1}{2}H}$	MEAN VELOCITY U	Discrepancy $v_{\frac{1}{2}H} - U$	Remarks
V.	10B.	4	5	5'·90—5'·95	3·46	3·39	+ ·07	
„	11B.	12	6	7'·25	3·75	3·70	+ ·05	
VI.	12B.	20	7	7'·55—7'·65	3·74	3·68	+ ·06	
VII.	13B.	22	8	8'·95—9'·0	4·26	4·17	+ ·09	
VIII.	14B.	20	9	9'·25—9'·5	4·07	4·02	+ ·05	
IX.	14BB.	20	9	9'·25—9'·5	4·07	3·99	+ ·08	

[The value of $v_{\frac{1}{2}H}$ here entered is the velocity at the middle of the depth of the deepest observations—(not that at the true mid-depth ($\frac{1}{2}H$)):—similarly U is—as previously—the mean velocity through the depth of deepest observation,—(not that through the real depth (H)].

It will be seen that the Difference between the Mid-depth Velocity and Mean Velocity in the central vertical plane is always a very small quantity *on the average of a large number of observations*, as expected from Result (30A), and always positive, (*i. e.*, $v_{\frac{1}{2}H} > U$).

The above Theory, depending on the parabolic form of the Curve does not lead to any expectation that this Result (30) would be true *of individual Sets*. To test this question, (raised in the Mississippi Report,) the "Mid-depth velocity," ($v_{\frac{1}{2}H}$) derived from each pair of Sets of Series 10B., 11B., 12B., 13B., 14B. is shown in Col. 10 of Tables V. to IX.; the SETS being combined by pairs to eliminate 'personal equation.'

By running the eye down this Col. (10) in these Tables it will be seen that this Mid-depth velocity is subject to variation from instant to instant quite similarly to the velocity at any other point: also by Col. 11 of these Tables it will be seen that the Difference between the Mid-depth and Mean Velocities ($v_{\frac{1}{2}H} - U$) is very far from being almost insensible or even constant from instant to instant.

[The Mississippi Experimenters seem to have been of opinion (*see* pages 294, 295, of Report) that the "Mid-depth Velocity", was sensibly constant from instant to instant, even under varying external conditions, (*e. g.*, *of Wind*), and nearly equal to (slightly greater than) the Mean velocity of the same vertical plane. The present Experiments, it will be seen, bear out only part of this conclusion, viz., as being true *only on the average*, and not from instant to instant].

This close approximation of the Mid-depth and Mean Velocities in the central vertical plane *on the average of a large number of observations* points to the measurement of "Mid-depth Velocity" as by far the quickest and most convenient way of measuring the Mean Velocity of this Vertical plane.

[This mode of measurement is proposed in the Mississippi Report, page 292, *et seq.*; the Authors appear to *assume* that this law is true *of all vertical planes*; but their reported Experiments are confined to the Mid-channel plane: it would be desirable to try this point by experiment. Time did not admit of doing so this season.]

63. Bottom-velocity.—The magnitude of the velocity at the Bed is a point of considerable importance, in both the theoretical and practical point of view. Unfortunately it cannot be directly measured. Were it quite certain that the "Vertical Velocity-curve" *really is a parabola*, the Bottom-velocity could of course be found from the equation (24) to the curve; thus there results, (if H = full depth),

$$\text{Bottom-velocity, } v_H = V - \frac{(H - Z)^2}{p}, \quad \ldots\ldots\ldots\ldots \quad (31),$$

in which the quantities Z, p are determined by velocity-observations as explained in Art. 60.

The Bottom-velocities have been calculated by this formula (31), for each of the Mean Curves of the Series 10 B., 12 B., 13 B., 14 B., 14 BB, and also by the well known formula

$$v_H = \frac{(\sqrt{12\, v_o} - 1)^2}{12} \quad \ldots\ldots\ldots\ldots \quad (31a),$$

and are exhibited together for comparison in following Table:—

Serial No.	Number of "Sets" in "Series".	Number of points of observation.	Mean Gauge-Depth (H).	Surface Velocity, v_o.	Assumed Max. Velocity, V.	Depth of Max. Velocity, Z.	Parameter of parabola, p.	Bottom Velocity v_H. By Formula, (31).	Bottom Velocity v_H. By Formula, (31a).
10 B.	4	5	5'·9	3·47	3·56	1'·25	16	2·21	2·48
12 B.	20	7	7'·6	3·80	3·87	1'·5	47	3·08	2·76
13 B.	22	8	8'·95	4·34	4·35	1'	79	3·55	3·22
14 B.	20	9	9'·45	4·25	4·25	0'	112	3·45	3·14
14 BB.	20	9	9'·45	4·25	4·33	1'·75	46	3·04	3·14

Much confidence cannot however—in the present state of experimental knowledge—be placed in the Results of formula (31), *based on the assumption* that the Vertical Velocity-Curve *really is a common parabola*, because all that can be said to be fairly established as yet is the limited Result (25) that *great part of the curve approximates* to such; it is doubtful whether this Result can be pushed beyond* the limit of actual experiment, to so critical a part of the Curve as that close to the Bed.

[In the parallel case of Surface Velocity-Curves, the peculiar form of the Curve would not have been established, had the Experiments not been continued *right up to the very margin*. In fact, were it not for the Experiments near the margin, the greater part of the Surface Velocity-Curve might have been supposed approximately a common parabola, as was actually supposed in the Mississippi Experiments (Report, page 237)].

It seems (to the Author) highly probable that the Curve may *change very rapidly close to the Bed*, so that the Bottom-velocity may be very small: up to the present time, Experiment has not been able to test this, as the practical difficulties are very considerable. There are, however, reasons for supposing that—in some natural channels—the Bottom-velocity is extremely small: thus over any soft Bed, *e. g.*, sand, earth, clay, there is a limit to the velocity which the Bed will stand, which over a sandy Bed at any rate is very small.

64. Other Vertical Velocity-Curves.—A few experiments were made in other vertical planes, besides the mid-channel plane already discussed: they were however too few in number to be worth inserting here. It would of course be very important to ascertain whether Results (21) of approximate constancy of Discharge and (30A) of approximation of Mid-depth and Mean Velocities were generally true of all vertical planes, and also to discover the form of the Vertical Velocity-curves.

So far as conclusions can be drawn from a limited number of experiments, it appeared that the line of maximum velocity is deeper seated towards the margin.

This Result is confirmed by experiments on MEAN VELOCITY, *see* end of Art. 73.

[This agrees with the Results of the Darcy-Bazin Report: the Mississippi Report does not discuss this].

65. Comparison of "Single Balls" and "Twin Balls".—Series 14 B. (with "Single Balls") and 14 BB. (with "Twin Balls") were executed together for this very purpose, the Instruments *being used together at every foot of depth* in the manner described in Art. 56, so that the Results might be comparable.

Tables VIII. and IX. show the detailed Results for each Instrument:

* For similar reasons, very little confidence can be put in *any now existing Formulæ or Tables* purporting to give value of Bottom-velocity.

those that seemed most worthy of comparison, viz., line (*a*) and Col. (9) have been brought forward from Table VIII. on to Table IX., as line (A) and Col. 9A, respectively.

Thus, Lines (*a*), (A), (*d*) of Table IX. show as follows :—

(*a*). The Mean of velocities at each foot of depth deduced from the "Twin Balls".

(A). The same by the Single Balls (brought forward from Table VIII.).

(*d*). The discrepancy between the above (A), (*a*).

These same Results are well shown in* the lower *Figure* of *Plate* VII., which exhibits the Vertical Velocity Mean Curves of Series 14 B., 14 BB. plotted *on the same Base-line.*

It is at once seen—either from the figure,* or from line (*d*) of Table IX.—that the discrepancy is *very marked*, and is just of the kind that would be expected on the supposition that—

(*a*). The Results by the "Twin Balls" are cleared of effect of Surface-action.

(A). The Results by the "Single Balls" are sensibly modified by the Surface-action on the Surface-float.

Thus, it will be seen that—

(1). Throughout the first few feet below the surface, where the velocity is greater than at the surface, the velocity as deduced from the "Twin Ball" *is uniformly greater* than that furnished by the Single Ball.

(2). Throughout the lower part of the Current, where the velocity is less than at the surface, the contrary takes place *uniformly*.

The discrepancies are so great, and *on the whole so regular*, that they cannot be overlooked. It may be, therefore, considered established that—

"The effect of surface-action on the "Single Ball" is not fairly negligible", (32).

On the other hand, it appears almost certain that the "Twin Balls", (as constructed in the present Experiments,) rather *exaggerates the effect of subsurface action* (*see* Art. 51); and, therefore, errs *in the opposite way to the "Single Ball"*.

On comparing the two Curves yielded by the "Twin Balls" and "Single Balls", (lower *Fig.* of *Plate* VII.), it will be at once remarked that the Curve yielded by the "Single Balls" is much the more regular of the two.

There is a strange irregularity at the 6′ depth in the Curve furnished by "Twin Balls", as to the cause of which the Author can give no explanation beyond the suggestion that possibly the Instruments were bady adjusted at this depth.

[The same care was, however, taken in preparing these as in those of other lengths].

* facing page 66.

On comparing the figures of Col. 8 of the two Tables VIII., IX., it will be at once seen that the values of the (superficial) Discharge through the 9′ depth, are all *much more nearly equal* by the "Single Ball" observations, than by the "Twin Balls" observations, that is to say, the Results of the latter are not nearly so regular as of the former.

This may be (partly) due to the irregularity at the 6′ depth just noticed: or to the unavoidable defect of the "Twin Balls" observations, arising from the impossibility of making the observation of the "Twin Balls" and their accompanying surface-float truly simultaneous or truly in same vertical plane.

[These last difficulties would be much enhanced in vertical planes distant from mid-channel].

[It is remarkable that the Mean Discharges of SERIES 14 B., 14 BB., as given by the "Single Balls" and "Twin Balls" differ very slightly (only — ·19 out of 36·14, *see* line (*d*), Col. 4, of Table IX.) It is, however, supposed that this can only be due to some accidental compensating influence for the Discharges of corresponding pairs of SETS, (compare Col. 7 of both the Tables VIII., IX.) differ by much more—(in one case by — 1·57 out of 36·30)].

The irregularities noticed, and the difficulty of making the observation with the "Twin Balls" *properly* (as required by the Theory) are decidedly unfavorable to the use of the "Twin Balls".

Remembering that the utility of the "Twin Balls" entirely depends on the correctness of the Theory of its use (Art. 49), and on the possibility of so observing as to nearly satisfy the requirements of that Theory, it seems (to the Author) that—notwithstanding the Conclusion (32) unfavorable to the "Single Balls", it is extremely doubtful whether the "Twin Balls" are a better Instrument.

66. Summary of comparisons of Instruments.—The discussion on the comparative merits of these Instruments has been detailed at considerable length, because it is little use making continued Experiments on a large scale, until confidence can be established in the Instruments with which the Experiments are done.

[The Instruments used in the Mississippi Experiments were all of the Class here called "Instruments of direct observation", and were very like the two used in these experiments under the name of "Single Balls" and "Tins". The American Experimenters give their opinion (Mississippi Report, pages 224, 244, 252), that the action of the surface-current on the surface-floats employed by them *is fairly negligible*: but no comparative Experiments are published in their Report justifying this statement. The Result of the present comparative Experiments with three Instruments ("Single Balls", "Tins" and "Twin Balls") must throw considerable doubt on it].

The general Conclusions are detailed in Arts. 43, 46, 51, and may be summed up thus:—

(1). The "Single Ball" satisfies all requisite conditions, except that the surface-action on it is not fairly negligible, ...

(2). The "Tin" satisfies condition of negligibility of surface-action *in the highest degree possible*, but fails both by not exposing a constant area to current, and by not straining its string properly, (so that its real depth is uncertain), ...

(3). The "Twin Balls" exaggerate subsurface action, and give irregular Results—their utility is entirely dependent on a hardly certain Theory, with the requirements of which it is very difficult to comply.....

67. *Improvement suggested.*—There can be no doubt that some of the irregularities in the present Experiments with both the SINGLE BALLS and TWIN BALLS are *due to the use of wood.*

From the experience gained in these Experiments, it would seem advisable to use metal instead. The chief objection to the use of metal is the expense, and the necessity of resort to a large workshop to have the Instruments made up and adjusted by skilled workmen. But the increased expease would be well worth the outlay if a more trustworthy Instrument were thereby provided.

On the whole, the SINGLE BALL (in metal) seems (to the Author) likely to be the best Instrument; as in consequence if its non-liability to absorb moisture if made in metal, the Surface-float could be so much reduced, that the principal defect of the Instrument would probably be removed.

Further comparative Experiments however seem desirable.

CHAPTER IV.

MEAN VELOCITIES.

68. Measurement of "Mean velocity" by Rods.—The use of a FLOATING STAFF loaded so as to float nearly upright is recommended in several works—*e. g.*,

Weisbach's Mechanics of Machinery and Engineering, Vol. I., Art. 376,
Royal Academy (Woolwich) Notes on Military Bridges, page 2,

for determining approximately the "MEAN VELOCITY" throughout its length.

The utility of this Instrument depends entirely on the question of whether the actual "velocity of the Rod" is, or is not, approximately the same as the MEAN VELOCITY throughout its length. The Instrument is so simple, so cheap, and so convenient in use (in currents not exceeding about 15′ deep), that if it does really measure MEAN VELOCITY (even approximately), it should *supersede all other* Subsurface "Free Instruments" when a knowledge of "mean velocity" only is required—(which knowledge is ample for the practical object of Discharge-measurement).

[No investigation of this question—nor even any reference to any investigation—is given in the works quoted, nor is the Author aware whether any investigation—either theoretical or practical—of this fundamental question has ever been published].

Many Experiments were, therefore, made to determine this point: the Theory of the motion will be first investigated.

69. *Theory of the motion of a "Rod".*—The Instrument consists essentially of a uniform slender cylindric ROD, loaded so as to sink vertically (in still water), *of uniform cross-section*, and *uniform physical state of surface* throughout its length.

When dropped into a uniform current, it penetrates into fluid strata moving with different velocities. After a time it will acquire a state of relative equilibrium with the fluid, after which it will move with a tolerably uniform velocity, and all parts of it will then have a common velocity.

Some of the fluid strata into which the ROD penetrates will be moving faster than the Rod, and some slower: the former will tend to accelerate

the Rod both by direct pressure and by friction; the latter will similarly tend to retard the Rod.

The Rod will, in consequence, move with a velocity which is *some sort of mean* of the velocities of those fluid strata; but the question is, will it move with what is technically understood as the MEAN VELOCITY of the fluid throughout its length?

It may be well here to define the term MEAN VELOCITY—

DEF. The "mean velocity" (U) throughout a depth (h) is equal to the (superficial Discharge (D) through that depth divided by the depth:

Or mathematically—

$$\text{Mean velocity through depth } h \text{ is } U = \frac{D}{h} = \frac{\int_0^h v\,ds}{h} \quad \ldots\ldots\ldots\ldots (33).$$

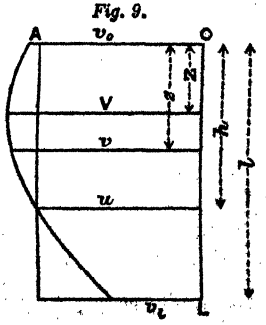
When the motion has become uniform, the two Total Forces of Acceleration and Retardation must of course be *equal and opposite*, so that they form a statical Couple, whose effect will be to rotate the Rod into an inclined position until the arm of the contrary Couple—consisting of the Weight of the Rod and the (equal opposite) Resultant upward Fluid Pressure is sufficient to produce a contrary moment of Stability just equal to the moment of Instability.

[For the above reason, at small depths of immersion, the Rod will incline *backwards*, at *one particular depth* only will float vertical, and at greater depths will incline *forward*. Also the lower the centre of gravity of the Rod is, the greater will be the Arm of the Couple of Stability for small inclinations, and the less therefore the Rod will incline: and if the centre of gravity be sufficiently low (as can always be secured in practice by making the Rod of a light material), the inclination will *always be very slight*. These Results are borne out by Experiment].

In the Investigation following, it will be supposed that the Rod is so loaded as to float *sensibly vertically*, so that its depth of immersion is sensibly the same as its immersed length.

Let b = breadth of cross-section of Rod,
s = depth of any fluid filament,
v = "velocity" of same,
u = "velocity" of Rod,
h = depth of fluid filament whose "velocity" is u,
v_o = surface-velocity,
l = length of Rod immersed = depth immersed (very nearly),
v_l = "velocity" at depth l,
V = maximum "velocity",
Z = depth of stream line of maximum velocity,

Fig. 9.



The figure represents the "velocity-curve" throughout the depth l; the (horizontal) abscissæ measured from OL, represent velocities, and the (vertical) ordinates measured from the surface OA represent depths.

Let it be supposed for the sake of distinctness that the Rod is so long, *i. e.*, penetrates into such deep strata, that it moves *slower than the surface current*, so that $u < v_o$.

Then the fluid from the surface to depth h (where the velocity of the rod and fluid are the same) accelerates the Rod, and the fluid below the depth h retards the Rod.

And $(v - u)$ = relative velocity of fluid filament, whose depth is not greater than h, past the Rod.

And $(u - v)$ = relative velocity of the Rod past any fluid filament whose depth is greater than h.

Now, considering only a small segment of the Rod of depth dz, it is clear that according to the best experimental Results as to "pressure" and "friction" of fluids in motion past solid bodies floating in them, (*see* Art. 49).

Pressure on small segment $= \pm k\,(v \sim u)^2\,bdz$,

Friction on small segment $= \pm \left\{\mu + \lambda\,(v \sim u)^2\right\} bdz$,

the $\pm$ sign being used according as $v > < u$, or $z < > h$.

$$\therefore \text{Total Acceleration on length } h = \int_o^h k\,(v-u)^2\,bdz + \int_o^h \left\{\mu + \lambda\,(v-u)^2\right\} bdz \quad \ldots\ldots (34\text{A}).$$

$$= P_o + F_o, \text{ (suppose).}$$

$$\text{Total Retardation on length } (l-h) = -\int_h^l k\,(u-v)^2\,bdz - \int_h^l \left\{\mu + \lambda\,(u-v)^2\right\} bdz \ldots (34\text{B}).$$

$$= P_1 + F_1, \text{ (suppose).}$$

$$\text{Retardation due to Friction on flat end of Rod,} = -\left\{\mu' + \lambda'\,(u - v_1)^2\right\} \cdot \frac{\pi b^2}{4} \quad \ldots\ldots (34\text{C})$$

$$= F_2 \text{ (suppose).}$$

And when the Rod has attained its state of relative equilibrium, it is clear that the algebraic sum of these must be zero, *i. e.*,

$$P_o + F_o + P_1 + F_1 + F_2 = 0, \quad \ldots\ldots (35).$$

But the last quantity (F_2) is so small—in a slender Rod—compared with the others as to be *fairly negligible*: omitting this term, and substituting the values of P_o, F_o, P_1, F_1, into (35) and re-arranging, and observing that k, μ, λ are *constant* throughout the length of the Rod—because it is supposed to be of uniform section and of uniform (physical) state of surface.

$$\mu b \left(\int_o^h dz - \int_h^l dz\right) + (k + \lambda)\, b \left\{\int_o^h (v-u)^2\,dz - \int_h^l (u-v)^2\,dz\right\} = 0,$$

whence after dividing by b,

$$\mu\,(2h - l) + (k + \lambda) \left\{\int_o^h (v-u)^2\,dz - \int_h^l (u-v)^2\,dz\right\} = 0 \ldots (36),$$

and this is the equation connecting the "velocity" (u) of the Rod with the various velocities (v) of the stream-lines.

This equation may be simplified by the following consideration. Ponselet's expression for the retardation due to friction of a fluid on a solid is $(\mu + \lambda V^2)$, from which it would *appear* that, in case of a solid at rest immersed in fluid at rest there is a *constant frictional retardation* $= \mu$, which is obviously absurd. It appears (to the Author) that this co-efficient μ should be zero. Adopting this correction, equation (32) reduces to—

$$\int_0^h (v-u)^2\,dz - \int_h^l (u-v)^2\,dz = 0, \quad \ldots\ldots\ldots\ldots\ldots\ldots (36A).$$

The velocity v at a depth z is, of course, some function of the depth z.

Expanding the above equation, and observing that u is constant and arranging—

$$\left(\int_0^h v^2\,dz - \int_h^l v^2\,dz\right) - 2u\left(\int_0^h v\,dz - \int_h^l v\,dz\right) + u^2\left(\int_0^h dz - \int_h^l dz\right) = 0,$$

whence is obtained a quadratic equation—

$$(2h-l)\,u^2 - 2\left(\int_0^h v\,dz - \int_h^l v\,dz\right)u + \left(\int_0^h v^2\,dz - \int_h^l u^2\,dz\right) = 0 \ldots\ldots (37),$$

by the solution of which the value for the velocity of the "Rod" might be obtained when the integrations had been performed.

This could not, of course, be done unless v were a *given function* of z. But without knowing the actual form of the function some useful Results may be found, thus—

There is no doubt *some particular length* (l) of Rod, for which the value $u = U$, *i.e.*,

$$\text{Velocity of Rod } (u) = \text{"Mean Velocity" } (U) = \int_0^l v\,dz \div l \ldots\ldots\ldots (38),$$

(on the truth of which the utility of the Rod depends)—satisfies equation (37), but, if Eq. 38 be true, this value ($u = U$) ought to satisfy Eq. (37,) *whatever be the length* (l) of the Rod.

Now, it seems impossible that v should be such a function of z that Eq. (37) should be *generally* satisfied by the value $u = U$ *for all values of* l.

The only functional form of v, for which this seems possible *for all values of* l is when $v = u = U$ (a constant quantity).

But all experiment shows that v *is never constant* throughout the depth, so that this case must be dismissed.

The general Result of all experiments up to the present day is that the "Vertical Velocity-Curve" is approximately a common parabola, so that the functional form of v is given by

$$(s - Z)^2 = p\,(V - v), \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (39)$$

It will be found that adopting this form for u, the value $u = U$ *will certainly not satisfy* the fundamental Equation (37), but the actual investigation is so tedious that it does not seem worth while publishing it, as the Result is simply negative.

The above reasoning points to the conclusion that—

"If the (at present) received laws of pressure and friction of moving fluids on solid bodies floating in them be correct, the "velocity" (u) of a floating uniform "Rod" is *not in general the same* as the mean velocity (U) throughout its depth", ... (40).

A further conclusion of some importance is, that since no use can be made of the fundamental equation, until the functional form of v is

and the integrations performed, experiments with "Rods" are not well suited to the discovery of that functional form, or in other words—

"Experiments with Rods are not well suited to discovery of the law of velocity-variation, ... (41).

They may, of course, be useful in testing the law when discovered by other means.

70. *Approximate Mean Velocity Measurement.*—Notwithstanding the conclusion that the velocity of a vertical uniform Rod is *not the same* as the 'mean velocity' throughout its depth, still the simplicity, cheapness, and convenience in use of a Rod is so great that for the practical purpose of measuring Discharge, *approximately*, its use would be very great if it could be shown that its "velocity" was even *approximately the same* as the "mean velocity" through its depth, *i. e.*, within the error admissible in practice.

It may be seen *à priori* that the discrepancy will probably *not be very* great.

The whole variation $(V - v_1)$ of the velocity from its maximum (V) to its value (v_1) at the foot of the Rod—(always the least in question if the Rod is long enough) is known by experiment with other Instruments to be *not very large.*

Also, the Rod's velocity (u), and the "mean velocity" (U) through the length l are known to be both $< V$ and $> v_1$ and therefore *can not differ greatly* from each other.

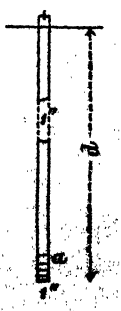
To calculate *à priori* the amount of discrepancy $(u - U)$ that may be expected would be almost impracticable on account of the great complexity of the equations to determine u.

This seems practicable (at present) only by experiment. Many Experiments were accordingly made with a view to determine this.

71. Description of the "Rods".—Two descriptions of these were used.

FIRST PATTERN.—A slender cylindric Rod of 1 inch diameter of a moderately heavy wood ("Sál", *Shorea robusta*) was loaded at one end (a) with small cylindric weights of the same diameter. The weights consisted of discs of sheet tin, and of small cylindrical pieces of lead of 1, 2, 4, 8 tolas weight, respectively; all of the same diameter (one inch). The weights (a) were secured at one end of the Rod by a long screw passing right through them all.

Fig. 10.



The Rod was loaded—by experiment in still water—until immersed—*including the length of the weights*—to the desired depth, leaving about an inch projecting above the surface.

A small screw was slightly screwed on to the head of the Rod to be used for attaching a small pledget of white cotton wool to serve as a "marker".

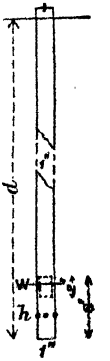
Rods of this pattern were prepared in sets of 1′, 2′, 3′, &c. ... 8′, 9′ depth of immersion.

The greater number of the Experiments with Rods were executed with Rods of this pattern.

They were found very convenient in handling: being portable, light, and occupying very little room.

[In these respects they contrast very favorably with the subsurface "Single Balls", and "Twin Balls" which—in consequence of their requiring to be laid out on large frameworks (Art. 41)—occupy so much room as to be very inconvenient in a small boat].

Fig. 11.



Improvement suggested.—The separation of the weights at the loaded end (*a*) is attended with the disadvantage of exposing an undue surface to friction against the current, as it is practically impossible to screw the separate pieces together so as to form one continuous piece of uniform section. Moreover, when once the weights are screwed on, the Rod cannot be readily adjusted to a different depth of immersion.

These defects would be both met by enclosing the leaden weights in a small tin or copper tube of same external diameter as the Rod, and about 8″ long: the Rod would be pared down a little at the end so as to slide in to the tube about 2″.

The tube would be secured to the Rod by a stout wire (w) running right through from side to side. Leaden weights, discs of tin, or small shot would be introduced as wanted by removing the tube.

Holes would be pierced in the tube as at *h* to admit the water freely.

Second pattern.—A few "Rods" formerly made up in the "Roorkee Workshops" for use of the Ganges Canal Officers, of a decidedly superior finish were lent for these Experiments from the Northern Division, Ganges Canal Office.

Fig. 12.



They were cylindrical wooden Rods, of 2½″ diameter, fitted with iron tubes at one end, into which bullets, shot, &c., could be introduced through a small hole closed by a small sliding iron shutter.

These Rods were neatly painted all over, and marked in feet and quarters of a foot.

They were made in Sets of only 3 (one 6′, one 9′, one 12′, long). These Rods were certainly superior in finish to those made up in the Bazar for the Author, but present little other advantage. The sliding shutter is easily damaged or lost, and the long

(12′) Rods are inconveniently heavy—owing to their large diameter. The main objection to them is their expense—about Rs. 10 each—in consequence of which they cannot be made up in sufficiently large numbers to be convenient.

[To work with any rapidity a stock of at least 4 Rods *of every length* 1′, 2′, 3′, &c., ...up to 9′ is required for the present Experiments].

72. Comparative Experiments with Rods.—These Experiments were made with the view of testing whether the "velocity" of the ROD is, or is not approximately the same as the MEAN VELOCITY (*see* Definition 33) of the fluid through its depth.

If this be true *generally*, it must obviously be true *for all depths of immersion*. It was decided, therefore, to test Rods along with other Instruments *at every foot of depth*.

The manner of performing the Experiments so as to secure fairly comparable observations, has been fully detailed in Art. 56. As there stated, the comparable Experiments (*i. e.*, those conducted at same time) bear the same Serial Number.

The details of the Experiments with the Rods will be found for SERIES 10 R., 11 R., 12 R. in Tables X., XI.

The details of the experiments with "Single Balls", which are comparable with these, viz., SERIES 10 B., 11 B., 12 B. are in Tables V., VI.

Lines D, A of these Tables (V., VI.) show the following—

(D). The (superficial) Discharge through 1′, 2′, 3′, 4′, 5′, 6′, 7′, 8′ of depth below the surface calculated from the observations (detailed in those Tables) of subsurface-velocity at every foot of depth with "Single Balls".

(A). "Mean velocity" through those depths calculated by dividing each Discharge (D) by the depth corresponding.

The Results in line (A) of Tables V., VI. are then transferred to Tables X., XI. for purposes of comparison.

Lines (*a*), (A), (*c*) under each Series in Tables X., XI., show the following—

(*a*). Mean of velocities of Rods of each foot of immersion.

(A). "Mean velocities" through those same depths as calculated from the observations with "Single Balls".

(*c*). Discrepancies between the two last (*a*), (A).

On examining the figures in this last line (*c*) under each of the SERIES (10 R., 11 R., 12 R.), it is seen that the "Discrepancies" between the two Results are—

(1), almost insensible through the first few feet below the surface.
(2), at first +, then −,
(3), and increasing (with the − sign) with the depth of immersion.
(4), not exceeding (within the limits of these experiments) — ·15 out of 3·70, or $\frac{1}{25}$rd part of the whole.

It is important to observe that the Discrepancy, small as it is, *tends to increase with the depth* submerged : because in practical use of Engineers, the "Rod" would be used only to measure the "mean velocity" *through the full depth of current*, and would therefore be submerged as much as possible, so that it would always be used—in practical usage—under circumstances giving Results most discrepant from those of the "Single Ball".

A more detailed comparison of the Result of the two Instruments *at the full depth* (the most important case) will therefore be useful.

This is given in Cols. 6, 8, 9 of Table X., XI.

Col. 6 shows the Velocity of longest Rod *of every pair* of "Sets" of observations combined so as to eliminate personal equation.
Col. 8 shows the "Mean Velocity" (Art. 69) calculated from the comparative experiments with "Single Balls" similarly freed from personal equation.
Col. 9 shows the discrepancy between the figures of Cols. 8, 6.

Comparing the figures in this last Column, it will be seen that—

"The velocity of the Rods at full depth is *constantly less by a well marked amount* than the "mean velocity" of that depth as calculated from nearly simultaneous observations with "Single Balls",..... ..(42).

This point (viz., the comparison of the velocity of the Rods at full depth with the "Mean Velocity" through that depth as found by other Instruments was yet further tested by the SERIES 14 B., 14 BB., 14 R. of experiments with "Single Balls", "Twin Balls" and Rods conducted together, as described in Art. (56). The details of each SERIES are shown in Tables VIII., IX., XII.: the only Results of Series 14 B., 14 BB. (viz., "Mean Velocity" through 9′ depth) suitable for comparison with Series 14 R. (observations with 9′ Rods) are brought forward from Tables VIII., IX., (Col. 9) to Table XII. (*see* Col. 7).

Thus Table XII., Cols. 6, 7, 8, show the following :—

Col. 6. The velocity of 9′ Rods for every pair of SETS of "velocity-measurements" combined so as to eliminate "personal equation".
Col. 7. The "Mean Velocities" through 9′ depth from the corresponding pairs of SETS of experiments with "Single Balls" and with "Twin Balls".
Col. 8. The Discrepancies between the figures of Cols. 6, 7.

TABLE X.

MEAN VELOCITIES IN VERTICAL PLANE.

SOLANI AQUEDUCT, LEFT CHAMBER—CENTRAL VERTICAL PLANE.

[*Instrument.*—1″ *Rod*].

1	2	3										4		5	6	7	8	9
Date 1875.	Gauge-depth.	MEAN VELOCITIES, (through depths named below). [Each Velocity is the mean of three observations]. Depths.										WIND.		Timekeeper's Initial.	MEAN VELOCITY By longest Rod (personal equation eliminated).	Diff. from Mean.	MEAN VELOCITY By "Single Balls," *see* Table V.	Discrepancy in Mean Velocity, at full depth by Balls and Rods.
		0	1	2	3	4	5	6	7	8	9	D	V					
18·2	5·95	3·45	3·57	3·40	3·40	3·26	3·40	..	..	..	..	S	8	W	3·43	+ ·12	3·38	+ ·05
„	5·90	3·45	3·61	3·40	3·53	3·40	3·45	..	..	..	..	S	15	R				
„	„	3·45	3·57	3·53	3·40	3·33	3·12	..	..	..	..	S	15	W	3·21	− ·16	3·40	− ·19
„	„	3·52	3·57	3·40	3·37	3·37	3·29	..	..	..	..	S	16	R				
a Means, ...		3·47	3·58	3·43	3·42	3·34	3·31	..	..	..	..							
A Mean Velocity by Balls, ...		3·47	3·51	3·53	3·51	3·45	3·39	..	..	..	..	From Table V., Series 10 B.						
c Discrepancy, ...		..	+ ·07	− ·10	− ·09	− ·11	− ·08	..	..	..	..							
19·2	7·25	3·85	3·92	3·85	3·85	3·90	3·70	3·57	..	..	..	..		W	3·51	− ·04	3·68	− ·17
„	„	3·90	3·85	3·90	3·70	3·80	3·57	3·45	..	..	..	S	8	R				
„	„	3·70	3·92	3·80	3·85	3·70	3·66	3·45	..	..	..	S	7	W	3·56	+ ·01	3·65	− ·09
„	„	3·66	3·70	3·95	3·85	3·75	3·66	3·66	..	..	..	S	7	R				
„	„	3·80	3·85	3·75	3·80	3·75	3·49	3·63	..	..	..	S	7	W	3·60	+ ·05	3·71	− ·11
„	„	3·70	3·85	3·80	3·70	3·75	3·70	3·57	..	..	..	S	9	R				
20·2	7·25	4·00	4·17	3·85	3·90	3·61	3·75	3·50	..	..	..	..	..	W	3·57	+ ·02	3·72	− ·15
„	„	3·85	3·77	3·70	3·85	3·95	3·80	3·63	..	..	..	S	5	R				
„	„	3·75	3·92	3·95	3·75	3·90	3·66	3·77	..	..	..	S	5	W	3·58	+ ·03	3·76	− ·18
„	„	3·70	4·08	3·95	3·80	3·80	3·75	3·38	..	..	..	..	..	R				
„	„	3·80	3·92	3·95	3·85	3·75	3·66	3·57	..	..	..	S	7	W	3·51	− ·04	3·67	− ·16
„	„	3·90	3·63	3·90	3·66	3·70	3·49	3·45	..	..	..	..	..	R				
a Means, ...		3·82	3·88	3·86	3·80	3·78	3·66	3·55	..	..	..							
A Mean Velocity by Balls, ...		3·82	3·85	3·87	3·96	3·81	3·76	3·70	..	..	..	From Table V., Series 11 B.						
c Discrepancy, ...		..	+ ·03	− ·01	− ·06	− ·03	− ·10	− ·15	..	..	..							

TABLE XI.

MEAN VELOCITIES IN VERTICAL PLANE.

SOLANI AQUEDUCT, RIGHT CHAMBER—CENTRAL VERTICAL PLANE.

[*Instrument.*—1″ *Rod.*]

Serial No.	1 Date 1875.	2 Gauge-depth.	3 MEAN VELOCITIES (through depths named below). [Each Velocity is the mean of three observations]. Depths. 0	1	2	3	4	5	6	7	8	9	4 WIND. D	V	5 Time-keeper's Initial.	6 MEAN VELOCITY By longest Rod (personal equation eliminated).	7 Difference from Mean.	8 MEAN VELOCITY "By Single Balls," see Table VI.	9 Discrepancy in Mean Velocity at full depth, by Balls and Rods.
SERIES 12 R.	22·2	7·65	4·00	3·80	3·95	4·00	3·85	3·85	3·50	3·70	..	..	V	15	W	3·68	+ ·11	3·68	..
	,,	,,	4·05	3·90	4·11	3·80	3·80	3·90	3·58	3·66	..	..	NE	20	R				
	23·2	7·55	3·80	3·70	3·80	3·80	3·57	3·70	3·70	3·66	..	..	..		W	3·58	+ ·01	3·69	— ·11
	,,	,,	3·75	3·85	3·85	3·95	3·80	3·70	3·70	3·49	..	..	..		R				
	,,	,,	3·85	3·85	3·95	3·70	3·61	3·66	3·70	3·23	..	..	..		W	3·52	— ·05	3·71	— ·19
	,,	,,	3·90	3·85	3·90	3·90	3·70	3·90	3·80	3·80	..	..	..		R				
	,,	,,	3·95	3·95	3·90	3·90	3·95	3·70	3·57	3·49	..	..	..		W	3·53	— ·04	3·65	— ·12
	,,	,,	3·90	4·05	4·00	3·85	3·80	3·85	3·70	3·57	..	..	..		R				
	24·2	7·55	3·75	3·80	3·70	3·80	4·00	3·49	3·80	3·49	..	..	..		W	3·55	— ·02	3·70	— ·15
	,,	7·58	3·66	3·70	3·80	4·00	3·85	3·70	3·85	3·61	..	..	SE	6	R				
	,,	7·60	3·60	3·75	3·90	3·90	3·80	3·85	3·70	3·66	..	..	SE	7	W	3·58	+ ·01	3·67	— ·09
	,,	,,	3·70	3·95	3·70	3·90	3·85	3·80	3·70	3·49	..	..	SE	6	R				
	,,	,,	3·70	3·70	3·75	4·00	3·90	3·57	3·41	3·57	..	..	SE	20	W	3·64	+ ·07	3·67	— ·03
	,,	,,	3·70	3·90	3·95	3·85	3·80	3·85	3·59	3·70	..	..	SE	17	R				
	26·2	7·60	3·85	3·90	3·90	3·80	3·75	3·70	3·70	3·61	..	..	E	13	W	3·53	— ·04	3·68	— ·15
	,,	,,	3·75	3·90	3·85	3·80	3·61	3·70	3·61	3·45	..	..	NW	9	R				
	,,	,,	3·66	3·75	3·75	3·85	3·80	3·66	3·70	3·41	..	..	W	10	W	3·51	— ·06	3·65	— ·14
	,,	,,	3·80	3·75	3·66	3·75	3·75	3·70	3·49	3·61	..	..	W	19	R				
	,,	,,	3·61	3·70	3·75	3·70	3·85	3·90	3·75	3·75	..	..	E/W	17/21	W	3·64	+ ·07	3·66	— ·02
	,,	,,	3·95	3·80	3·66	3·80	3·80	3·66	3·53	3·53	..	..	W	19	R				
a Means, ...			3·80	3·83	3·84	3·85	3·79	3·74	3·64	3·57									
A Mean Velocity by Balls, ...			3·80	3·83	3·85	3·84	3·82	3·78	3·75	3·68						From Table VI., Series 12 R.			
c Discrepancy, ...			...	...	— ·01	+ ·01	— ·03	— ·04	— ·11	— ·11									

TABLE XII.

MEAN VELOCITIES IN VERTICAL PLANE.

SOLANI AQUEDUCT, LEFT CHAMBER—CENTRAL VERTICAL PLANE.

[*Instrument.*—1″ *Rod*].

Serial No.	1	2	3	4	5	6	7		8	
	Date 1876.	Gauge-depth.	Velocity of 9′ Rod.	WIND. D V	Timekeeper's Initial.	Velocity of 9′ Rod (pers. eqn. eliminated).	MEAN VELOCITY through 9′ depth. By "Single Balls," *see* Table VIII.	By "Twin Balls," *see* Table IX.	Discrepancy of Rod-Velocity and Mean Velocity. By Single Balls.	By Twin Balls.
SERIES 14 R.	5·4	9·50	3·95	..	R	3·85	4·03	3·86	— ·18	— ·01
	„	„	3·74	S b W 8	W					
	6·4	9·50	3·79	..	R	3·79	3·99	4·04	— ·20	— ·25
	„	„	3·73	..	W					
	„	„	3·83	..	R	3·82	3·97	3·87	— ·15	— ·05
	7·4	9·50	3·81	..	W					
	„	„	3·92	..	R	3·83	4·02	4·07	— ·19	— ·24
	„	„	3·74	..	W					
	8·4	9·50	3·90	S W 3	R	3·65	4·07	4·05	— ·42	— ·40
	„	„	3·40	V 30	W					
	9·4	9·50	3·59	..	R	3·68	4·00	4·05	— ·32	— ·37
	„	„	3·77	..	W					
	10·4	9·50	3·73	..	R	3·71	4·03	4·00	— ·32	— ·29
	„	„	3·68	..	W					
	12·4	9·40	3·75	..	R	3·73	3·99	3·88	— ·26	— ·15
	„	„	3·70	..	W					
	14·4	9·40	3·87	..	R	3·85	4·03	4·08	— ·18	— ·13
	„	„	3·83	..	W					
	15·4	9·25	3·85	..	R	3·86	4·03	4·05	— ·17	— ·19
	„	„	3·87	..	W					
	8 Means, ..		3·77	..	..	3·77	4·02	3·99	— ·25	— ·22

The figures in this last Column bear out the previous Conclusion (42).

Thus from the *regularity of the variation* of the Discrepancy in SERIES 10 R., 11 R., 12 R, and from its being—at full depth *constantly negative* by a well marked amount, *averaging*

— ·07 in 3·38, — ·15 in 3·70, — ·12 in 3·69, — ·25 in 4·02,

in the Means of the Series 10 R., 11 R., 12 R., 14 R (*see* line (*c*) of Tables) it may be concluded that—

"The velocity of a ROD is not the same as the MEAN VELOCITY of its depth of immersion, but differs by an amount *increasing with depths of immersion*, and also *with depth of channel*", ... (42).

Hence it follows that—

"A ROD is useless as an *Instrument of precision* for measurement of Mean Velocity", ... (43).

The error varying *on the averages* in the present experiments from $\frac{1}{47}$ to $\frac{1}{16}$ of the whole is much larger than the Difference between the Mid-depth Velocity ($v_{\frac{1}{2}H}$) and Mean Velocity (U) established by experiment (Art. 62): it does not, however, seem so great as to interfere with its use in practice of Engineers for measurement of MEAN VELOCITY when required solely for Discharge calculation, for it is quite doubtful whether any existing Discharge formulæ will give values of Discharge, within the above limits of error.

[*N.B.*—It must be remembered that in all the comparisons here cited, the Experiments were not quite crucial as to *full depth of channel*, for on account of the vertical oscillations of the Rods, it was necessary to leave them about 6″ clear of the bottom (as shown by the Standing Gauge) to prevent their coming in contact with the occasional inequalities of silt: on the other hand the Experiments show that the Discrepancy *increases with the depth of immersion*].

73. Discharge-Measurement by Rods.—TWO SERIES of Experiments were made at the Centre Cross-Section of the Left Chamber of the Solání Aqueduct on Measurement of Discharge by RODS.

The RODS used in these two SERIES were of the "Second pattern", described in Art. (71), admitting of adjustment with shot to any desired depth. They were sunk to within about 6″ of the bottom.

The Mode and Order of observation was quite similar to that used in investigating the Surface-velocity Curves described in Art. 27, *et seq.*; thus the RODS were passed along vertical planes at 16 places, whose distances from the centre were as below:—

SOLANI AQUEDUCT, LEFT CHAMBER, CENTRE SECTION,
Half breadth 42′·5.

Left of Centre.	Centre.	Right of Centre.
39′½, 37′½, 35′, 32′½, 30′, 20′, 10′,	C	10′, 20′, 30′, 32′½, 35′, 37′½, 40′, 41′½,

[The corbelling out of the footway on the left bank prevented the Rods being run outside the 40′ of centre line, and when the Canal rose above 9′ depth, the only Rods longer than 9′ (at the time available for use) were so long (12′) as to come in contact with the projecting masonry, so that velocity-measurements could not be continued along this line].

The RODS were placed in the water so as to assume their nearly erect final position as quietly as possible: there was, however, always a small vertical oscillation even whilst passing over the "Standard Run"—not exceeding about 2″ whilst in the Run. To provide for this vertical oscillation without allowing the ROD to come in contact with the occasional silt on the Bed, it was found necessary to allow the foot of the Rod to be about 6″ clear of the Bed (as shown by the Standing Gauge).

[Even with this "windage" the RODS occasionally struck the silt just before reaching the upper Rope, or even within the "Run": the observation of a Rod so striking *was not recorded.*]

The RODS were run by threes along each of the vertical planes above indicated: the mean of the velocities of three Rods in same vertical plane was considered one Mean velocity-measurement freed from observation-errors. Velocity-Measurements were extended across the channel so as to form a SET, and the SETS were arranged into SERIES precisely in the manner described in Arts. (29, 30) for Surface-Velocities.

Two such SERIES, Nos. 15 R., 16 R. were executed. The detailed Results are exhibited in Table XIII.

The area of the Curve resulting from plotting the Velocity-Measurements of each SET was separately calculated by the usual approximate formulæ, and the (cubic) DISCHARGE was found by multiplying each of these areas by the corresponding gauge-depth, (and is printed in Col. 4).

The MEAN VELOCITY (of the Section) was found by dividing the Curve-Area by the breadth of the channel (85′),—which is of course equivalent to dividing the (cubic) DISCHARGE by the Section-area.

TABLE

MEAN VELOCITIES

Solani Aqueduct, Left Chamber

Serial No.	1	2	3											
	Date 1874-76.	Gauge-depth.	Mean Velocities of [Each velocity measurement is											
			Left of centre.							Centre.	Right			
			42½	40	37½	35	32½	30	20	10		10	20	30	32½
Series 15 R.	19·3	8·90	..	3·33	3·45	3·57	3·57	3·57	3·61	3·80	3·53	3·57	3·75	3·70	3·61
	20·3	8·90	..	3·28	3·51	3·41	3·68	3·77	3·61	3·68	3·85	3·70	3·75	3·64	3·57
	„	„	..	3·33	3·61	3·61	3·61	3·75	3·61	3·75	3·70	3·70	3·85	3·70	3·66
	„	„	..	3·47	3·41	3·61	3·66	3·57	3·77	3·73	3·77	3·85	3·55	3·66	3·68
	22·3	9·10	..	3·41	3·45	3·61	3·70	3·80	3·75	3·85	4·00	3·57	3·53	3·57	3·61
	„	„	..	3·39	3·43	3·59	3·66	3·80	3·77	3·90	3·90	3·66	3·75	3·77	3·75
	23·3	9·15	..	3·39	3·45	3·57	3·45	3·66	3·75	3·66	3·85	3·95	3·23	3·61	3·70
	„	„	..	3·37	3·49	3·53	3·70	3·59	3·85	3·85	3·95	3·85	3·73	3·66	3·73
	24·3	9·15	..	3·41	3·45	3·61	3·70	3·70	3·75	3·75	3·75	3·57	3·70	3·70	3·57
	„	„	..	3·33	3·53	3·59	3·66	3·75	3·55	3·75	3·87	3·77	3·59	3·92	3·66
	25·3	9·10	..	3·49	3·53	3·80	3·61	3·66	3·80	3·70	3·80	3·53	3·90	3·49	3·80
	..	..	..	3·43	3·68	3·61	3·82	3·70	3·66	3·87	3·68	3·87	3·59	3·59	3·66
	a Means,	..		3·39	3·50	3·59	3·65	3·69	3·71	3·77	3·80	3·72	3·66	3·67	3·67
Series 16 R.	29·3	9·50	..	..	3·23	3·26	3·49	3·61	3·80	3·95	4·00	3·90	4·00	3·85	3·8
	„	„	..	..	3·14	3·31	3·57	3·51	3·80	3·90	3·92	4·03	4·03	4·00	4·0
	30·3	9·65	..	..	3·30	3·30	3·49	3·57	3·66	3·85	3·70	3·80	3·90	3·95	3·8
	„	„	..	..	3·23	3·28	3·37	3·53	3·87	4·00	3·66	3·90	3·80	4·05	3·9
	31·3	9·70	..	..	3·45	3·53	3·53	3·70	3·75	3·66	3·85	3·75	3·90	3·66	3·7
	„	„	..	..	3·17	3·26	3·61	3·73	3·77	3·87	3·64	3·68	3·57	3·77	3·7
	1·4	9·70	..	..	3·03	3·30	3·30	3·49	3·61	3·66	3·57	3·95	3·75	3·57	3·8
	„	„	..	..	3·09	3·28	3·37	3·33	3·59	3·73	3·70	3·68	3·85	3·66	3·7
	2·4	9·75	..	..	3·19	3·30	3·26	3·45	3·45	3·75	3·75	3·53	3·66	3·75	3·7
	„	„	..	..	3·06	3·21	3·83	3·37	3·64	3·64	3·82	3·70	3·43	3·59	3·8
	3·4	9·50	..	..	3·19	3·23	3·41	3·41	3·80	3·75	3·37	3·61	3·70	3·61	3·7
	„	„	..	..	3·30	3·23	3·26	3·43	3·73	3·77	3·85	3·55	3·47	3·61	3·1
	a Means,	..	..	..	3·20	3·29	3·42	3·51	3·71	3·79	3·74	3·76	3·76	3·76	3·

XIII.

AND DISCHARGES.

CENTRAL SECTION.—[*Instrument.—2½" Rod*].

VERTICAL PLANES. the mean of three observations]. of centre.					4	5	6	7	8	9	10	11	12
35	37½	40	41½	42½	TOTAL DISCHARGE in cubic ft. per sec.	WIND. D V	Timekeeper's Initial.	MEAN VELOCITY.	MEAN VELOCITY perel. equn. eliminated.	Diff. from Mean	Central surface Velocity (observed) v_o	MEAN VELOCITY by Bazin's Rule, perel. equn. eliminated.	Discrepancy of Columns 8, 11.
3·61	3·57	3·41	..	..	2670·62	..	R	3·53	3·57	−·05	Not observed.		
3·64	3·57	3·31	..	..	2725·54	..	W	3·60					
3·66	3·61	3·49	..	..	2731·14	..	R	3·61	3·60	−·02			
3·64	3·59	3·59	..	..	2720·20	..	W	3·59					
3·57	3·61	3·41	..	..	2746·72	..	R	3·63	3·66	+·04			
3·68	3·66	3·51	..	..	2780·36	..	W	3·68					
3·75	3·53	3·45	3·09	..	2762·66	..	R	3·55	3·62	·00	..		
3·55	3·59	3·49	3·21	..	2873·01	..	W	3·69					
3·57	3·61	3·45	3·03	..	2810·79	..	R	3·61	3·61	−·01	4·17	3·50	−·11
3·73	3·57	3·45	3·06	..	2806·85	..	W	3·61			4·17		
3·57	3·66	3·53	3·13	..	2842·02	..	R	3·67	3·64	+·02	4·41	3·76	+·12
3·61	3·64	3·47	3·21	..	2782·69	N 20	W	3·60			4·55		
3·63	3·60	3·46	3·12					3·62	3·62			3·63	+·01
3·70	3·61	3·61	3·26	..	2995·16	..	R	3·71	3·72	+·15	4·35	3·65	−·07
3·95	3·90	3·66	3·39	..	3012·74	..	W	3·73			4·35		
3·85	3·57	3·53	3·23	..	2954·06	..	R	3·60	3·62	+·05	4·38	3·75	+·13
3·64	3·66	3·77	3·30	..	2974·13	..	W	3·63			4·53		
3·75	3·61	3·53	3·19	..	3005·25	..	R	3·64	3·59	+·02	4·38	3·70	+·11
3·70	3·55	3·41	3·28	..	2915·43	..	W	3·54			4·43		
3·61	3·61	3·41	3·06	..	2875·96	..	R	3·49	3·51	−·06	4 32	3·63	+·12
3·73	3·73	3·39	3·33	..	2914·56	V 20	W	3·53			4·32		
3·61	3·75	3·37	3·23	..	2890·49	..	R	3·49	3·48	−·09	4·22	3·60	+·12
3·55	3·47	3·33	3·11	..	2874·50	..	W	3·47			4·35		
3·70	3·70	3·33	3·13	..	2804·12	..	R	3·47	3·50	−·07	4·22	3·61	+·11
3·77	3·57	3·64	3·00	..	2844·49	..	W	3·52			4·38		
3·71	3·64	3·50	3·21	..	..	..	..	3·57	3·57	..	..	3·66	+·09

An examination of this Table will show Results quite similar to those enumerated in the discussion of the Surface-velocity Experiments, Art. 29, *et seq.*, thus:—

1°. The velocity of the Rod *in any one plane* varies very much from SET to SET under the same external conditions (*see* any of the narrow columns under Col. 3 of Table).

2°. The Rod-velocity Curves are individually of irregular shape and disagree in detail—(*see* Col. 3 of Table).

3°. The (cubic) Discharge through the transverse Section, and therefore also the Mean Velocity of the section (found by dividing the cubic Discharge by the Section-area) are tolerably constant, the chief discrepancies from their Mean Values being apparently due to the observers' 'personal equation'—*see* Col. 4, 7 of Table—and disappearing to a great extent after elimination of 'personal equations', *see* Col. 8, so that these experiments accord with the otherwise known Result.

"Cubic Discharge" and "Mean Velocity" through the Cross-section = constant.

4°. The MEAN CURVE of a SERIES of SETS is a pretty regular Curve, notwithstanding the irregularity of the individuals of the Series.

[To calculate these Areas an assumption had of course to be made as to the magnitude of the mean-velocity in the vertical planes *at the margins*, (not obtainable by direct measurement). This mean-velocity was *assumed zero* at both margins. As to the correctness of this assumption, nothing is known, but the error (if any) will not seriously affect the quantity required, (the whole Area of the Curve,) as the marginal spaces affected are both narrow].

The Mean Curves resulting from the SERIES 15 R., 16 R., are shown in *Plate* IX. (the clear lines): their extreme flatness is very remarkable; the Mean-velocity scarcely varies notably over $\frac{7}{8}$ of the width of the channel.

In the SERIES 15 R. in which the depth is the greater (9'·63) there is a curious very marked diminution of the velocities on the left, and increase of those on the right, of the channel as compared with the SERIES 15 R. with the lesser depth (9'·05): the cause of this is not understood, but it is probably some local peculiarity due to the position of the Channels of supply into, and discharge from, the 932' chamber, in which the Experimental Section lay—(*see Fig.* 3, *Plate* I.)

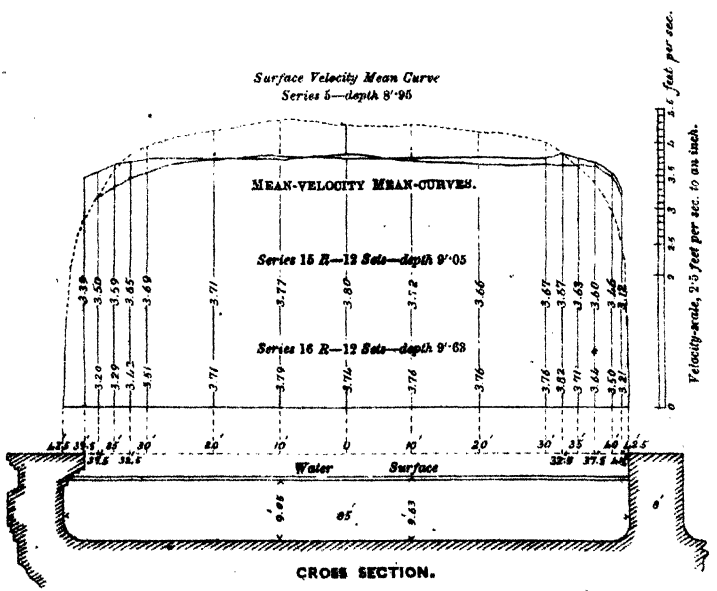
The Surface-velocity Mean Curve for a depth of 9' at same section has been drawn (a dotted line) on same Base line to contrast with the present Curves. It will be observed that the Mean-Velocity Mean Curves lie within the Surface-Velocity Mean Curve through nearly $\frac{7}{8}$ of the width of the Channel, and then pass outside it; and that, therefore, the

HYDRAULIC EXPERIMENTS AT ROORKEE.

MEAN-VELOCITY MEAN-CURVE

at Centre-section of Left Chamber of Solání Aqueduct.

Abscissæ indicate distances from the centre of the Cross-section.
Ordinates indicate velocities.
Mean-velocity Mean-curves and Ordinates, in clear lines.
Surface-velocity Mean-curve, and Ordinates, in dotted lines.
Scale for Cross-section and Abscissæ, 25 feet to an inch.
Scale for Ordinates (velocities), 2·5 feet to an inch.



Mean Velocity (of a vertical plane) is less than the Surface-velocity over about $\frac{7}{8}$ of the width, and is greater outside this.

This clearly shows that the line of maximum velocity (in a vertical plane) is highest in the mid-channel vertical plane, and is *more and more deep seated* in vertical planes further from mid-channel.

[This bears out what was stated Art. (64), as seeming probable from a limited number of experiments with "Balls", and agrees with the French Experiments.]

74. Discharge by "Rods", and by Bazin's Formula.—SERIES 15 R., 16 R., of Experiments with Rods were undertaken for the express purpose of testing extant formulæ. As these formulæ all furnish a value of the MEAN VELOCITY (of the Section), it will be sufficient to compare these values.

For this purpose the central surface-velocity was—(except in the first few SETS)—found by 6 observations at end of each SET of observations with Rods. The means of these 6 is recorded in Col. 10 of Table XIII., as the surface-velocity corresponding to each SET of Rod-observations.

Bazin's Rule* for finding the MEAN-VELOCITY (U)—*from observations of central surface-velocity* (v_o) is

$$U = c\, v_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (44).$$

where c is a co-efficient depending both on the 'hydraulic mean-depth' and on the nature of the sides and bed, and which is stated* to be $c = \cdot 84$ for a channel *with masonry sides and bed* (which nearly corresponds to the case of the Solání Aqueduct) *with 'hydraulic mean depth' of* 7'·4 ($= 9' \times 85' \div (9' + 85' + 9')$.

The MEAN VELOCITIES so calculated are shown in Col. 11 of Table XIII., deduced from the observed Surface-Velocities (Col. 10) combined by pairs so as to eliminate 'personal equation.'

The Discrepancy between the MEAN VELOCITY as deduced from the Experiments with Rods (Col. 8), and as calculated from Bazin's Formula (Col. 11) are shown in Col. 12.

It will be seen that the Results of Bazin's Formula are *generally higher* by $\frac{1}{30}$ of the whole, and on the average of one SERIES (No. 16 R.), higher by only $\frac{1}{40}$ th part. It may be inferred that—

* *See* Darcy-Bazin Report, pages 157 to 161, and Table No. 4, page 329; or N. W. P., P. W. Irrigation Circular, No. U of 1874, pages 2, 3, and Table II.

"Bazin's Formula ($U = c \cdot v_0$) gives the MEAN VELOCITY from observations of central surface-velocity in rectangular masonry channels of large size (85' wide) and of 'hydraulic mean depth' about 7'·5, at least as correctly as it can be measured by numerous observations with Rods,"..... (45).

[There are no Results in the Mississippi Report which can be compared with the figures of Table XIII., the directions in the Mississippi Report being in fact to compute DISCHARGE by observations of MEAN VELOCITIES in many vertical planes, as has been here attempted by use of RODS. It would be very desirable to attempt the measurement of Discharge by measuring Mid-depth Velocities (Art. 62) as recommended in the Mississippi Report. Time did not admit of this this season].

75. Vertical Velocity-Curves.—The Experiments with Rods at every foot of depth were so numerous, (Series 10 R., 11 R., 12 R.) that it was hoped that the forms of the Vertical Velocity-Curve might be investigated from them. An attempt was made in this direction to calculate the velocity at each foot of depth from the observations with Rods by a slight modification of the Theory of Art. (69), (which is supposed to be the most correct now obtainable).

To apply this, it was necessary—since the RODS were used only at each successive foot of depth—to make the additional hypothesis that the effect on the Rod's motion was the same as if the velocity were uniform throughout each foot of depth, and then suddenly varied.

[Some such hypothesis must always necessarily be made in reduction of observations at points separated by finite intervals].

By the repeated application of (Eq. 36A), which may for this purpose be written—

$$\Sigma \pm (v - u)^2 = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (36B),$$

the velocities (v_1, v_2, v_3, &c.,) at middle of each successive foot of depth were calculated.

The Results were—as perhaps might be expected from the rough nature of the hypothesis made above—very far from regular.

As the calculation, though simple, is very laborious, it seems unnecessary, in consequence of the irregularity of the Results, to explain it in detail.

It will suffice to say that the general Result was similar to that shown by use of the "Twin Balls", Art. 65,—as might be expected, since the Theory here adopted for the motion of the "Twin Balls" and "Rods", (Art. 65, 69), is identical in principle,—viz., that the Vertical Velocity

Curve deduced from use of the "Single Balls" was *too flat*; the Curve resulting from the calculation just explained was *in the main* similar to that resulting from the use of the "Twin Balls," *see* lower *Fig.* of *Plate* VII.

It will be seen also that Result (41) is hereby established, that—

"Experiments with Rods are not well suited to discovery of velocity-variation,"..... } ..... (14).

CHAPER V.

SUMMARY AND CONCLUSION.

76. Summary of Results.—For facility of reference a Summary of the Results of this Paper are here collected: the Results are not arranged in the order in which they occur in the Text, but in that which seemed most convenient for exhibiting the Results at one view:—

	Art.	Result No.
The term VELOCITY in Hydraulics means usually only the Resolved part of the Actual Velocity parallel to the axis of the current; for mere Discharge-measurement this is a more useful quantity than the actual Velocity.	**8**	DEF.
FIXED INSTRUMENTS are—in consequence of the delicacy of observation required—in general (the "Current Metre" excepted) suitable only to positions where a steady support can be secured; *i. e.*, only to small streams, and to observations close to margin in large streams.	**12**—I	
FREE INSTRUMENTS are alone suited in general to large streams.	**12**—II	
FREE INSTRUMENTS do not measure the VELOCITY at a point but only the AVERAGE VELOCITY (the term Velocity being taken as above defined) along the Stream-line throughout their Run: for mere Discharge-measurement this is quite as useful a quantity as the resolved part of the actual Velocity at a point would be.	**12**—II	2
No '**Free** Instrument' yet invented for measurement of Sub-surface-velocity in a large stream is quite satisfactory.	**37**	
The Conditions which should be fulfilled by an Instrument of "direct observation" are essentially inconsistent, and can therefore be only partially satisfied together.	**38**	7°—10°
Instruments of "Indirect observation" labor under the disadvantage of depending on some hypothesis of law of fluid pressure. Most "Fixed Instruments" have this disadvantage.	**39**	

	Art.	Result No.
Of the four Subsurface-Instruments tried, and *as constructed for these experiments*:—		
The "Single Ball" fulfils all conditions except—(the most important for an Instrument of "direct observation")—that its surface-float is not small enough for the effect of surface-action on it to be fairly negligible.	43 65 66	
The "Tin" fulfils that condition in the highest possible degree, but fails in not exposing a constant surface directly and laterally to the current, and in not retaining itself at a constant known depth.	46 66	
The "Twin Balls" depend for their utility on a hardly certain Theory, and the observational requirements of that Theory are very difficult to fulfil: they are, therefore, liable to more irregularity than the "Single Ball".	51 65 66	
Wood is too hygroscopic to be a really suitable material for these Instruments for delicate observations: metal would be preferable.	42 67	
The "Single Ball" made in metal would probably be as good a Subsurface "Free Instrument" as could be desired.	67	
The "Rod" is not well suited for experiments to investigate laws of fluid motion,	69	41
and is useless as an Instrument of precision for measurement of Mean Velocity of a vertical plane;	69 72	40 43
but the discrepancy between the Velocity of a Rod and the Mean Velocity through its length is not so great as to interfere seriously with its practical use for Discharge-measurement.	72	
The Motion of a large body of water is UNSTEADY, (even in a uniform channel of great length), *i. e.*, the velocity at a point varies considerably from instant to instant.	25	3
Single Velocity-measurements are therefore incomparable unless simultaneous, a condition generally impracticable.	25	4
The AVERAGE VELOCITY at a point taken through a long interval of time, is sensibly constant under similar external conditions (of wind, depth, &c.)	26	5
Average-Velocity-measurements derived from very numerous observations are therefore alone comparable, and not single measurements.	26	6
Hydraulic Experiments in general must therefore necessarily be very tedious and consequently very expensive.	26	7
Comparative Experiments with different Instruments are therefore also very tedious.	54	
Horizontal Velocity-Curves and Vertical Velocity-Curves depending on single Velocity-measurements are very irregular.	29 57	
But the areas of the Surface Velocity-Curve and Mid-channel Vertical Velocity-Curve (computed from many ordinates	30	

	Art.	Result No.
i. e., velocities measured—not simultaneously—but in succession) are approximately constant.	58	
There is a probability, therefore, that the (superficial) Discharges across the surface, and in the mid-channel Vertical plane are approximately constant.	30 59	8 21
The Surface-Velocity Mean Curve is strikingly regular and is symmetrical about mid-channel in a symmetric uniform channel of great length.	31	
Its form depends on the figure of the cross-section.	31	
In a very wide channel (breadth not $< 9 \times$ depth), it is a very flat Curve.	33 34	
In a rectangular section in masonry with a depth $= \frac{2}{3}$ of breadth it is approximately a "quartic ellipse" whose equation is $\frac{u^4}{u_0^4} + \frac{y^4}{b^4} = 1$	33	11
The Surface-Discharge in same case $= \cdot 927 \times$ Central Surface-Velocity $\times$ Surface breadth.	33	12
The Surface-velocity near the margin decreases very rapidly with proximity to the margin, and at the margin itself is extremely small, perhaps zero in case of straight margins of great length.	35	14
There is a constant surface-motion from the margin towards the centre, most intense at the margin.	35	15
The AVERAGE CENTRAL SURFACE-VELOCITY varies at same place on a calm day nearly as the square root of the central depth, or as the square root of the hydraulic mean depth.	36	16
The Mid-channel Vertical Velocity Mean Curve is strikingly regular, and is approximately a common parabola, whose equation is— $(z - Z)^2 = p\,(V - v)$	60	24
whose Axis is usually below the surface at a depth (Z) depending on the state of the wind,	61	
and whose parameter increases very rapidly with the depth.	61	
The Mid-channel Mid-depth Velocity is variable from instant to instant,	62	
but the average of the same through a long time exceeds the Mid-channel Vertical Plane Mean Velocity (U) by a very small fraction; and is, therefore, convenient as a practical measure of that Mean Velocity.	62 62	30
The form of the Curve is hardly well enough determined (to be a *common* parabola) to admit of the Bottom Velocity being thence inferred.	63	
The line of maximum Velocity of a Vertical Plane is highest at Mid-channel, and is more and more deep-seated further from Mid-channel.	64 73	

	Art.	Result No.
The Velocity of a "Rod" is variable from instant to instant but its average velocity over a long time is sensibly constant.	72 72	
Mean Velocity Curves depending on single Mean velocity-measurements are irregular.	73	1°, 2°
But their Area is nearly constant, showing that the (cubic) Discharge is nearly constant.	73	3°
The Mean Velocity Mean Curve is very regular, and very much flatter than the Surface-Velocity Mean Curve.	73	4°
The Mean Velocity of a rectangular section, 85' × 9', in masonry, computed from Mean Velocity-measurements with (Rods) does not differ from the Mean Velocity of the Darcy-Bazin Results more than the probable observation-errors.	74	44

77. Further Experiments desirable.—LIMITATION NECESSARY.—The present Experiments lasting only four months, are of course only a small contribution to EXPERIMENTAL HYDRAULICS. It is to be hoped that they will be only the beginning of an extensive Series of Experiments in India, prolonged over several years under varied conditions on a large scale.

The Text will have shown numerous points on which further Experiment is very desirable. But some limitation seems urgently required to prevent Experiments being too diffuse, so as to secure some practically useful Result within a reasonable time.

It might seem for instance desirable for the advancement of HYDRAULIC SCIENCE to aim at the discovery of the

"FIGURE and SIZE of the "Velocity-Surface" for the most "useful cross-sections in masonry and earth in a "uniform Channel of great length",

giving thereby the "velocity" (u) at any point of a cross-section as a function of—

(a), the central surface velocity (u_o),
(b) the co-ordinates (y, z) of the point,
(c), the several dimensions (b, H, &c.,) of the cross-section.

So that in fact, f being now a known function

$$u = f(u_o, y, z, b, \text{H}, \&c.)$$

from which the Discharge would be at once calculable by reduction of the expression,

$$\text{D} = ff, u, dy, dz,$$

which might be done in a form suited to practical men once for all.

Nevertheless, it appears to the Author—after the experience of this

season—that the above Result could not be looked for within any reasonable Expenditure of time and money, unless some very much more expeditious mode of ascertaining the AVERAGE VELOCITY along a "stream line" can be discovered then by the use of Floats, as in these Experiments.

[Thus it appears from Art. 33, that about a fortnight's work is necessary for the discovery of the FIGURE and SIZE of a single "Horizontal Velocity Mean Curve", so that the establishment of the FIGURE and SIZE of the whole "Velocity-Surface" would necessarily take many weeks, during which the Canal must be maintained *of uniform depth of flow* at the chosen section].

This will be understood to be the consequence of the motion of water not being technically STEADY, but only an AVERAGE STEADY MOTION.

[The important consequences of this were of course only gradually realized in the course of these Experiments.

78. Direction of Experiment recommended.—The following seems to the Author the best Course for future Experiments in order, to realize some practically useful Results with a reasonable expenditure of time and money, viz.:

1°. "To verify whether the MEAN VELOCITY *past any vertical whatever* is approximately the same as the mid-depth 'velocity' on that vertical."

2°. "To verify whether a 'Rod' sunk to nearly full depth measures approximately the MEAN VELOCITY of its plane of motion, *in any vertical plane whatever.*"

At present these two facts can only be said to have been verified (by the Mississippi Experiments, and by the present Experiments) *for the mid-channel plane.*

If either 1° or 2° can be verified *for all vertical planes* (as well as the Mid-channel plane), practically useful Results could be comparatively rapidly developed. Thus experiments would then be directed (as in Art. 73) to ascertaining the

"FIGURE and SIZE of the MEAN VELOCITY MEAN CURVE for the most useful Cross-sections in masonry and earth in a uniform channel of great length", ...

giving thereby the MEAN VELOCITY (U) *on any vertical line* as a function of

(*a*), the mid-channel MEAN VELOCIT (U_o),
(*b*), the abcisse (y) of the line.
(*c*), the several dimensions (b, H, &c.) of the cross-section.

Besides which, Experiments would be required towards determining the

Mid-channel Mean Velocity (U_o) as a function of the central Surface-Velocity (u_o), and of the several dimensions (b, H, &c.) of the cross-section.....

So that in fact f, ϕ being then known functions,

$$U = f(U_o, y, b, H, \&c.\ldots\ldots),$$

$$U_o = \phi(u_o, H, \&c.)$$

From which U would be calculable in terms of the known dimensions (b, H, &c.) of the cross-section, and of a *single* (the central) surface-velocity (u_o) to be obtained *by actual observation.*

Such a MEAN CURVE could (it is believed) be generally determined *for any one central depth* with sufficient accuracy in about a fortnight's work, provided the canal could be kept running steadily at one level throughout that time.

For *each foot of central depth*, the MEAN-VELOCITY MEAN CURVE should be separately determined.

This would complete the really necessary Experiments at one section.

79. CANAL EXIGENCIES.—The requirements of Canal administration would certainly not admit of a Canal being run at one level for a fortnight, and then *at successively lower levels, foot by foot, for a fortnight each* (or whatever the time required might be).

But, it is presumed, that Canal requirements would admit of a Canal being run *at different levels constant for a considerable period together* at different seasons of the year. If this be feasible, it would be quite possible by continuing experiments through more than 12 months, to gradually obtain a fairly complete Set of the MEAN-VELOCITY MEAN CURVES, for a number of different sections, the observing party shifting from section to section as fast as one MEAN CURVE was completed, so long as the Canal remained of constant level, and retracing their steps over the same ground, when the Canal level was altered.

In this manner the MEAN-VELOCITY MEAN CURVES for several different central depths might be determined at several of the most useful sections in the course of a year.

80. Preliminary Experiments on Instruments required.—But before projecting Experiments on this large scale, preliminary Experiments are urgently required on the various means of measuring Subsurface-Velocity, as it is no use making Experiments on a large scale until Instruments have been discovered, which will command general confidence.

Some means of greatly increasing the rapidity of observation, *i. e.*, of arriving at the Result really required, viz., the AVERAGE VELOCITY in a

Stream Line, much more quickly than by the tedious Method used in these Experiments, is also a desideratum.

The rapidity of observation with FREE INSTRUMENTS (Floats) could not be greatly increased, without reverting to the Two Chronometer Method, which would greatly increase the labor of reduction.

The only Instrument which seems likely to meet this desideratum—of giving the AVERAGE VELOCITY tolerably rapidly,—in a large Canal or River, is the Current Metre, which was successfully employed by M. Révy in the Paraná Experiments.

81. Expense of Experiments.—The present (four months') Experiments have cost up to date about Rs. 1320.

But, in consequence of the small scale on which they were done, it has been possible to do them *at a much smaller proportionate cost* than could be managed, if the scale were increased; most of the expensive "Plant" having been lent to the Author on this occasion, a favor that could not be looked for on a larger scale; the chief expenditure has, in fact, been on Establishment.

The cost of an "observing unit" may be estimated as follows, excluding the cost of Superintendence:

PLANT.	RS.
2 Chronometers, @ Rs. 700	1,400
2 Boats, @ Rs. 350	700
1 Anemometer, @ Rs. 100	100
5 Chains, Surveying, @ Rs. 10	50
2 Twelve-Foot Rods, @ Rs. 5	10
1 Pitot's Tube, with latest improvements	150
1 Current Metre, ditto ditto	150
2 Tents and Necessary	450
Petty Apparatus (Floats, Rods, &c.,)	500

ESTABLISHMENT AND CONTINGENCIES.		
2 European Overseers, @ Rs. 125	250	350 per month.
9 Boatmen and "Classies," @ Rs. 5 and 4 ..	40	
Contingencies	60	

The charge for PLANT would of course be incurred, once for all, but that for ESTABLISHMENT would be continuous, amounting to Rs. 3,000 annually for one "observing unit."

Additional spare Plant should of course be provided as in case of injury or fracture of any of the original Plant, the whole Party *would be*

thrown temporarily (or even permanently) *out of work*, and the expensive Establishment charges needlessly incurred.

82. *Acknowledgment of assistance.*—The Author's obligations are due to several of the officials of the neighbourhood for assistance and advice: especially to Major A. M. Lang, R.E., Principal of the Thomason C. E. College, for allowing these Experiments to be superintended by the Author concurrently with his College duties, (without which permission they could not have been done at all): also to the Commandant, Bengal Sappers and Miners (Colonel F. R. Maunsell, C.B., R.E.) for the loan of a Non-Commissioned Officer as an additional Observer: to the Superintending Engineers of Irrigation (R. Forrest, Esq., and Major C. C. Scott Moncrieff, R.E.): to the Superintendent Roorkee Workshops (A. Campbell, Esq,): and to the Executive Engineer, Northern Division, Ganges Canal (Capt. J. H. Western, R.E.), for the loan of some of the more expensive Plant (Boat, Chronometer, Anemometer, &c).