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MAJOR A. M. BRANDRETH, R.E.,
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No. CCXLVII.

REMOVAL OF CLEOPATRA'S NEEDLE.

[*Vide* Plates I. and II.]

The accompanying Plates and Note, were supplied by A. B. Sampson, Esq., B.A., Under Secretary to Government of India, P. W. Department.

Now that the removal of Cleopatra's needle has been a matter of interest, the accompanying facsimile copies of drawings found among the records of the old Military Board may also be interesting. The drawing of the capstan is not quite clear: it probably works on a pivot at the bottom, and in the cross piece at the top. The inventor, or at all events the man who used the arrangement at Ghazipur, was Captain Garstin, Bengal Engineers, in the year 1819. A somewhat similar plan was proposed for the removal of Cleopatra's needle in the *Scientific American*, July 3rd, 1875, entitled "A Monument at Sea."

Extract from Scientific American, July 3rd, 1875.

"Several years ago the famous obelisk, known as Cleopatra's needle, was donated by the Egyptian to the British Government, but the latter, although several plans have been proposed, has heretofore considered no scheme as overcoming the Engineering difficulties of removing the monolith from its present site near Alexandria to the shore, and thence transporting it by sea to England. We learn from the London *Times* that an attempt is now shortly to be made, and the project which has been adopted is as follows:—The obelisk, which is quadrilateral in shape, is first to be changed into a cylinder. This will be done by attaching heavy beams, strongly connected together, to each face, until the desired form is obtained, the work being continued very carefully, and excavations

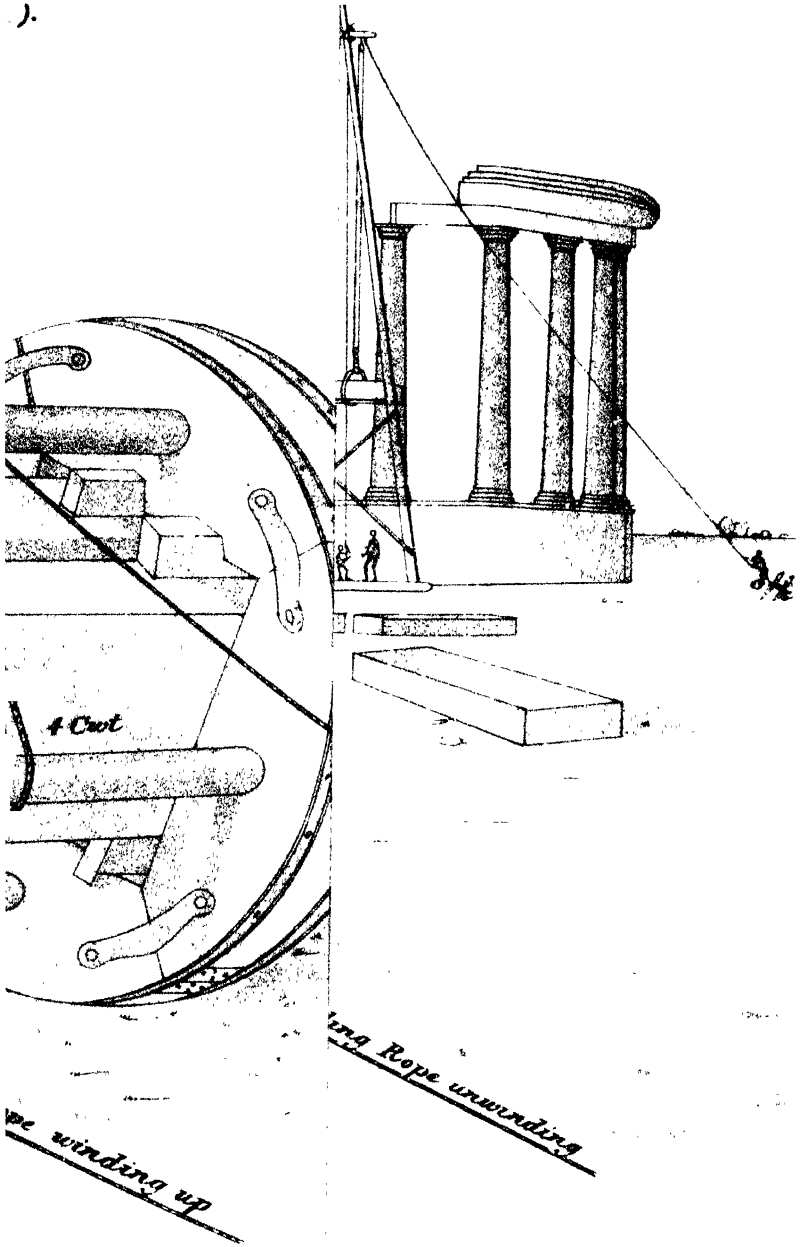
being made, little by little, until the entire shaft, from apex to foundation, is enveloped. It will not be difficult then to roll the monument over a wooden road, laid over the sand hills which cover the intervening mile between its present location and the sea.

"The wooden envelope, while increasing the mass will, at the same time be such as to diminish the specific gravity of the whole, so that the great bundle will readily float. To this end, the diameter of the circle formed by a section of the cylinder will be 20 feet, or 12 feet larger than the breadth of the sides of the obelisk. Besides, in order to render the line of flotation horizontal, a diameter exceeding 20 feet will be necessary at the heavier base.

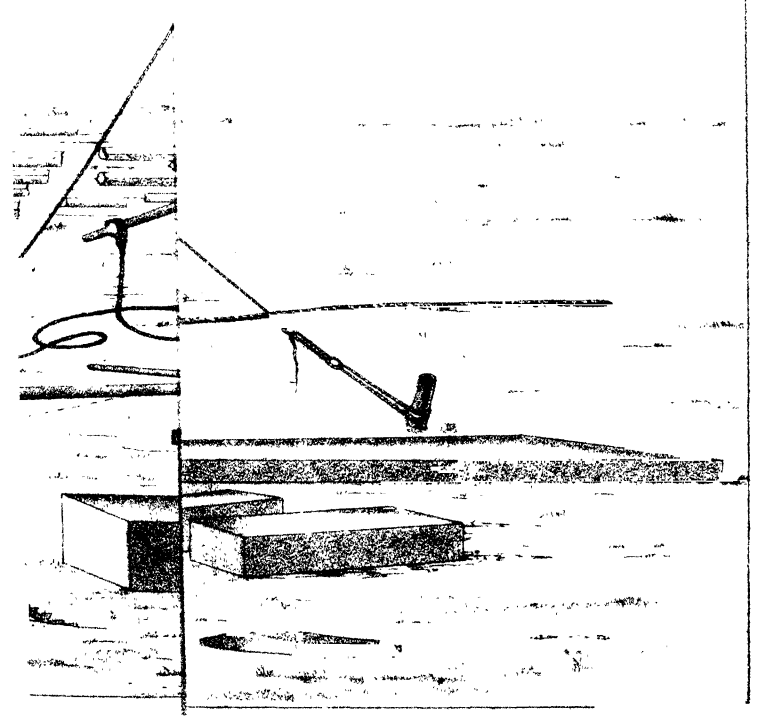
"After the monument is launched, it will be towed out of the Mediterranean and into the Thames, to the nearest point to its future site. It will then be beached and rolled to its position, where it will be erected before removing its coverings.

"This plan, it is believed, can be carried out very easily and with little expense, while it will be free from the dangers found in transporting the Obelisk of Luxor to Paris, as during its voyage that monument seriously damaged the vessel."

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PSTAN,
Ghazipur, 1819



No. CCXLVIII.

COMPARATIVE STATEMENT OF DIMENSIONS AND COST OF STORAGE WORKS IN THE DECCAN.

By Walter C. Hughes, Esq., C.E., *Asst. Chief Engineer for Irrigation, Bombay.*

Memo. by Col. C. J. Merriman, R.E., *Chief Engr. for* No. 5320 of 1877.

The accompanying Statement of dimensions and cost of storage works constructed, under construction, or proposed, in the Bombay Deccan, is submitted for the information of Government, with a view to its being circulated for the information of the Department.

The Statement is a revision of that submitted in 1871 by Colonel Fife,* with this exception, that it comprises information in respect of the storage works only and not their canals or distributaries, regarding which a separate Statement is proposed to be prepared. It may be noted that this Statement gives the actual cost of the completed works, and includes a large number of schemes investigated since the preparation of the former Statement. It is also more complete in giving details of dimensions of the works.

The information will be of extreme value in considering the merits of future proposals here or elsewhere.

* Government Resolution No. 47 I.–524 of 1871.

No.	Col	OF CONTOURS LLIONS OF RE FEET. At outlet level	Total capacity in millions of cubic feet.	Available capacity in millions of cubic feet.	Cost of water stored per million cubic feet.	No.	REMARKS.
1		18	19	20	21	22	23
1	Poon	60·625	5,226·076	3,476·076	500	1	Completed. Actual cost.
2	Sholi	25·625	5,020·041	4,763·791	255	2	In progress.
3	Bhor	10·656	4,641·698	4,153·496	354	3	Proposed.
4	Sholi	12·211	3,350·030	3,330·030	227	4	Completed. Actual cost.
5	Satar	15·875	3,095·250	2,952·594	474	5	Proposed.
6	,,	48·508	3,072·134	2,632·770	304	6	In progress.
7	Khan	3·260	1,576·480	1,560·177	388	7	Proposed.
8	Sholi	11·953	1,499·470	1,419·384	302	8	In progress.
9	Satar	3·400	522·643	489·777	639	9	Do.
10	Poon	6·080	369·621	367·493	338	10	Do.
11	Khan	.....	367·952	367·952	708	11	Completed. Actual cost.
12		3·920	351·383	294·485	679	12	Proposed.
13	Satar	3·520	310·418	290·002	744	13	Do.
14	,,	0·370	298·279	296·429	1,309	14	Condemned.
15	Poon	0·360	230·011	228·760	649	15	In progress.
16	,,	0·313	223·269	222·328	542	16	Do.
17	Satar	1·125	200·865	195·241	925	17	In progress.
18	,,	1·200	195·275	190·475	981	18	Completed. Actual cost.
19	Khan	0·790	160·962	158·571	433	19	In progress.
20	Dhar	0·764	140·614	136·411	489 571	20	Rejected for special reason. Sanctioned.
21	Ahm	1·616	110·683	103·678	966	21	Condemned.
22	Sholi	2·033	91·725	81·561	1,171	22	Water-supply. Completed. Actual cost.
23	Khan	0·050	68·044	67·894	1,099	23	Water-supply. In progress
24	Dhar	1·120	62·384	57·600	660	24	In progress.
25	Poon	1·110	43·752	36·352	3,510	25	Water-supply. Completed. Actual cost.
26	Satar	0·470	25·236	24·501	1,631	26	In progress.
27	Poon	0·087	15·000	14·800	2,103	27	Water-supply. In progress

mn 16 by 19.

No. CCXLIX.

PROPOSED MEDICAL SCHOOL FOR LAHORE.

[*Vide* Plates III., IV. and V.]

Designed by Rai Bahadur Kunhya Lall, *Assoc. Inst. C.E., Exec. Engineer, P. W. Department, Punjab.*

The accompanying *Plates* Nos. III., IV. and V., show the design for a Medical School, proposed to be built at Lahore to the south of the Mayo Hospital, a description of which was given in Paper No. L. of this Series for October 1872.

This design is in exact keeping with the Mayo Hospital, and the style of its architecture is "*Italian*," same as that of the Hospital. The Hospital is a two-storied building, with five towers, one in the middle, and one at each of the four corners, which added greatly to its cost. The School is to have no towers, but merely rooms and verandah, which are necessary and useful.

The design has been approved and sanctioned by the Punjab Government, and is to be carried out so soon as funds are made available for it.

The building contains eight principal rooms as follows:—

Library and Office, ...	54 ft. × 32 ft.
Lecture Room for Anatomy, and also for instructions of Hindústaní class, ...	42 „ × 34 „
Medical and Surgical Lecture room, ...	42 „ × 22 „
Chemical Lecture room, ...	42 „ × 22 „
Anatomical Museum, ...	43 „ × 20 „
Chemical and Materia Medica Museum, ...	43 „ × 20 „
Laboratory, ...	42 „ × 20 „
Room for Meteorological Instruments, ...	42 „ × 20 „

Injecting and dissecting rooms are to be provided in a separate building, to be built at a distance from both the School and the Hospital.

The object of constructing the building is to provide suitable accommodation for the Lahore Medical School, which is now held in a private building, rented for the purpose, which does not afford the accommodation required.

The details of the construction of this building are to be exactly the same as those of the Mayo Hospital, described in Paper No. L. of this Series, and the accompanying Abstract gives the different quantities of work in the building, together with rates and probable cost of each class of work, as well as of the entire building.

Abstract of probable cost of Proposed New

No.	Schedule number.		Description of work.	Rate.	MEDICAL SCHOOL.		OUT-HOUSES TO MEDICAL SCHOOL.	
					Quantity.	Cost.	Quantity.	Cost.
				RS.		RS.		RS.
			I. Earthwork.					
1	I	2	Excavation of foundation, c. ft.,	3/- °/₀₀	1,80,696	542	3,015	9
			II. Road metal.					
2	II	1 to 4	Brick metalling, ... c. ft.,	4/- °/₀	..	..	..	..
3	„	„	Kankar, ... „	8/- „	..	..	..	..
			IV. Bricklayers' work.					
4	IV	47	Concrete work in foundation, ... c. ft.,	12/- °/₀	43,641	5,237	..	..
5	„	1	Burnt bricks in lime mortar in foundation, .. „	20/- „	36,710·25	7,342	..	..
6	„	2	„ „ „ } „ „ „ in plinth, } „	25/- „	11,541	2,885	..	..
7	„	11	„ „ „ } „ „ „ in steps, } „	36/- „	5,586	2,010	..	..
8	„	4	„ „ „ } „ „ „ in superstructure, 1st class, .. } „	30/- „	95,559	28,668	..	..
9	„	30	„ „ „ } „ „ „ in superstructure, 2nd class, .. } „	24/- „	..	..	1,013·88	243
10	„	26	„ „ in verandah arched roof, .. „	30/- „	12,300·5	3,690	..	..
11	„	15	Fine dressed cornices, 21″ girth, ... r. ft.,	-/12 ft.,	878	658	..	..
12	„	14	„ „ 18″ girth, „	-/8 „	844	422	..	..
13	„	„	„ inner „ 18″ „ „	-/8 „	1,442	721	..	..
14	„	6	Ornamental work below cornices, ...	40/- °/₀	4,390	1,756	..	..
15	„	7	Open ornamental railings above roof, ... „	43/- „	4,599	1,977	..	..
16	„	7	Ornamental parapet of verandah roof, ... „	45/- „	4,390	1,975	..	..
17	„	13	String courses of pillars, „	-/4 ft.,	1,096	274	..	..
18	„	38to 39	Burnt bricks in mud mortar in foundation, .. c. ft.,	8/- °/₀	..	..	2,236	179
19	„	41	„ „ in superstructure, ... „	9/- „	..	..	5,216·20	469
20	„	14	Outer cornices, 18″ girth, r. ft.,	-/6 ft.,	..	..	360·50	135
			Carried over, ..	..	..	58,157	..	1,030

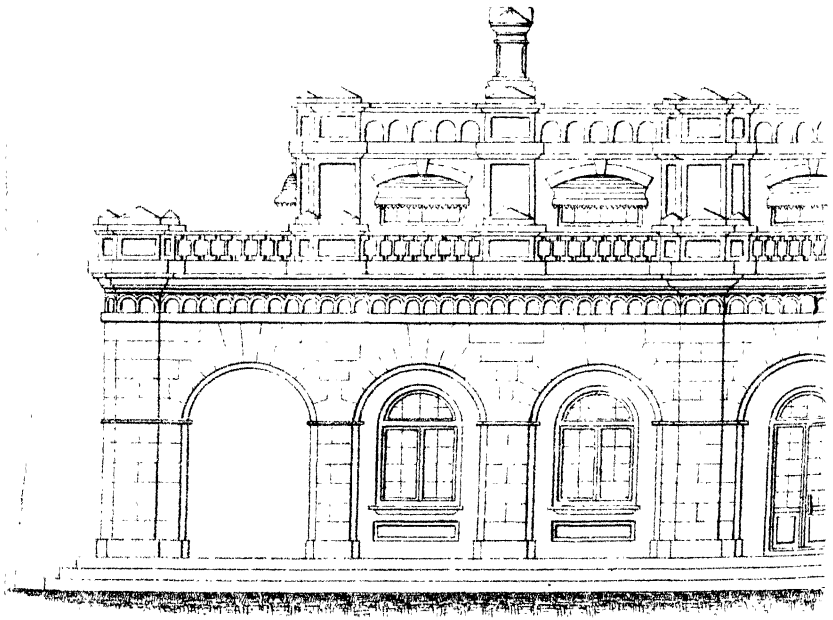
edical School and Out buildings at Lahore.

MPOUND WALL ID GATEWAYS.		CLEARING AND LEVELLING SITE.		APPROACHES.		TOTAL.		TOTAL OF EACH CLASS OF WORK.		Remarks.
antity.	Cost.	Quantity.	Cost.	Quantity.	Cost.	Quantity.	Cost.	Quantity.	Cost.	
	RS.		RS.		RS.		RS.		RS.	
342	95	8,90,340	2,671	..	..	11,05,693	3,317	..	3,317	
..	..	..	..	10,720	429	10,720	429	..	..	
..	..	..	..	8,040	643	8,040	643	..	1,072	
85·5	2,278	..	..	..	..	62,626·5	7,515	..	..	
93	1,398	..	..	..	..	43,703·25	8,740	..	..	
92	1,398	..	..	..	..	17,133	4,283	..	..	
.	..	..	..	..	..	5,586	2,010	..	..	
94·7	628	..	..	..	..	97,653·75	29,296	..	..	
50	2,916	..	..	..	..	13,163·88	3,159	..	..	
.	..	..	..	.	..	12,300·5	3,690	..	..	
.	..	..	..	..	..	878	658	..	..	
.	..	..	..	..	..	844	422	..	..	
.	..	..	..	..	..	1,442	721	..	..	
.	..	..	..	..	..	4,390	1,756	..	..	
.	..	..	..	..	..	4,599	1,977	..	..	
.	..	..	..	..	..	4,390	1,975	..	..	
.	..	..	..	..	..	1,096	274	..	..	
	..	..	..	..	..	2,236	179	..	..	
	..	..	..	..	..	5,216·20	469	..	..	
	..	..	..	..	..	360·50	135	..	67,259	
	8,713	..	2,671	..	1,072	..	71,648	..	71,648	

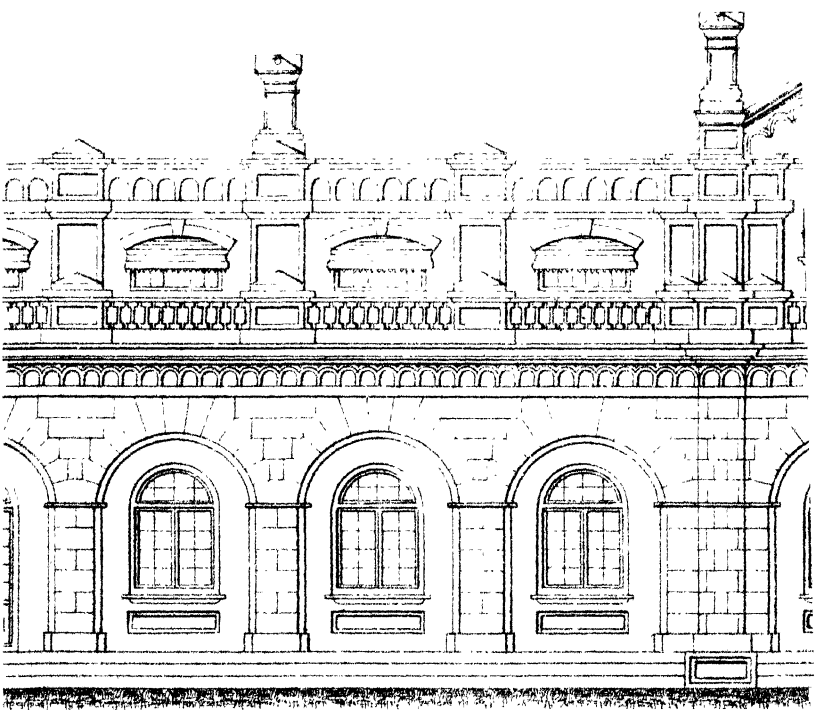
No.	Schedule number.	Description of work.	Rate.	Medical School.		Out-houses Medical Sch.	
				Quantity.	Cost.	Quantity.	C
					Rs.		F
		Brought forward, ..	..	..	78,732	..	1,
		X. Carpenters' and Joiners' works.—(Continued.)					
40	X	4 Fixed louvres, ... s. ft.,	1/4 ft.,	1,358·86	1,699	..	.
41	„	31 Doors and windows, .. „	1- „	3,950	3,950	..	.
42	„	42 Battened doors, ... „	-/8 „	..	..	96	
43	„	55 Windows, wooden, barred, with shutter inside, .. „	-/8 „	..	..	16	
44	„	58 Sunshades, ... No.	7/- each.	56	392	..	.
45	„	53 Pankah frames, 1st class, „	-/10 ft.	1,276	797	..	.
		XI. Smiths' work.					
				m. s.			
46	XI	12 Iron for girders, fixed, .. s. ft,	20/- md.,	132 0	2,640	..	.
47	„	12 „ for trusses, ... „	20/- „	200 13½	4,006	..	.
48	„	22 Zinc sheets of ventilator for Library and office, „	-/8 ft.	537	268	..	.
49	„	„ Ironwork of ornamental ridging for Library and office, ... r. ft.,	6/- „	54	324	..	.
50	„	„ Perforated ridge, .. „	3/- „	50	150	..	.
		XII. Painting and Glazing.					
51	XII	19 Spirit varnish of doors and windows, .. r. ft.,	4/- %	5,677·78	227	..	
52	„	9 White painting of wood-work of roofs, ... „	4/- „	9,078	363	..	
53	„	8 Green painting of towers, „	1/8 „	3,038·86	45	..	.
54	„	23 Glazing of doors and windows, ... „	-/4 ft.,	3,326·78	831	..	.
		Total, ..	..	..	94,424	..	1
		Add 5 per cent. for Contingencies, ...	..	..	4,721	..	
		Total, ..	..	..	99,145	..	1
		Compensation for buildings, ..	..	..	..	..	
		GRAND TOTAL, ..	..	..	..	..	

'D WALL 'EWAYS.	CLEARING AND LEVELLING SITE.		APPROACHES.		TOTAL.		TOTAL OF EACH CLASS OF WORK.		Remarks.
Cost.	Quantity.	Cost.	Quantity.	Cost.	Quantity.	Cost.	Quantity.	Cost.	
RS. 8,973	..	RS. 2,671	..	RS. 1,072	..	RS. 93,094	..	RS. 80,842	
..	..	..	..	..	1,358·86	1,699	..	..	
..	..	..	..	..	3,950	3,950	..	..	
..	..	..	..	..	96	48	..	..	
..	..	..	..	..	16	8	..	..	
..	..	..	..	..	56	392	..	..	
..	..	..	..	..	1,276	797	..	19,146	
210	..	..	..	..	m. s. 142 20	2,850	..	..	
900	..	..	..	..	245 13½	4,906	..	..	
..	..	..	..	..	537	268	..	..	
..	..	..	..	..	54	324	..	..	
..	..	..	..	..	50	150	..	8,498	
..	..	..	..	..	5,677·78	227	..	..	
..	..	..	..	..	9,078	363	..	..	
..	..	..	..	..	3,038·86	45	..	..	
..	..	..	..	..	3,326·78	831	..	1,466	
10,083	..	2,671	..	1,072	..	1,09,952	..	1,09,952	
504	..	133	..	54	..	5,497	..	5,497	
10,587	..	2,804	..	1,126	..	1,15,449	..	1,15,449	
..	..	..	..	..	..	..	..	762	
..	..	..	..	..	..	..	..	1,16,211	

K. L.



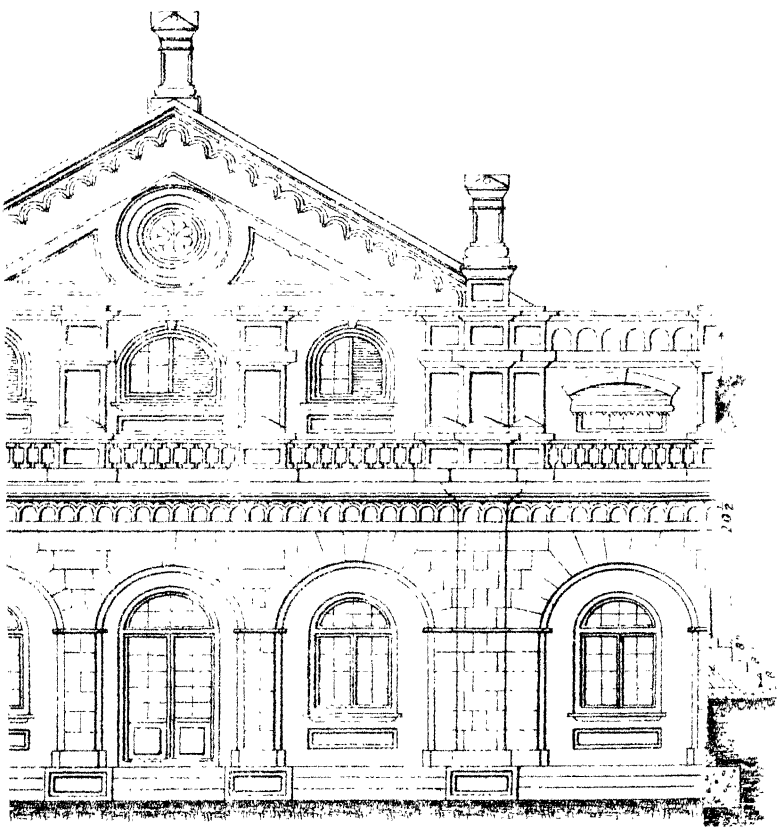
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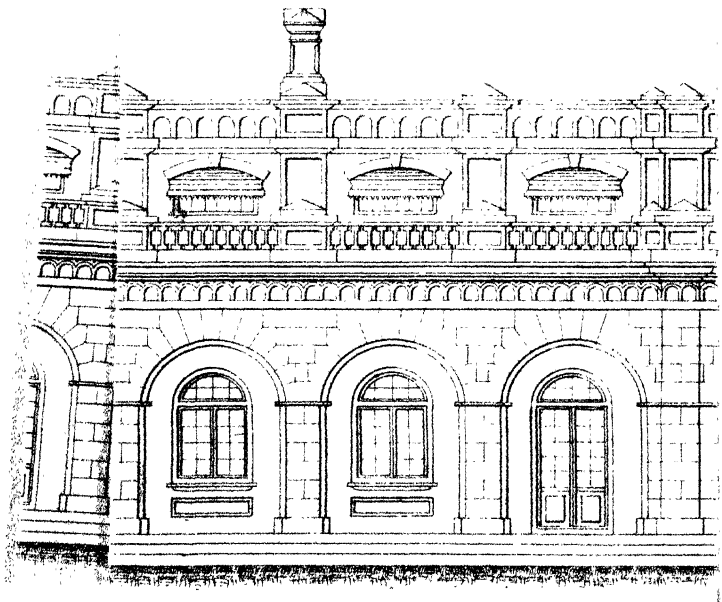


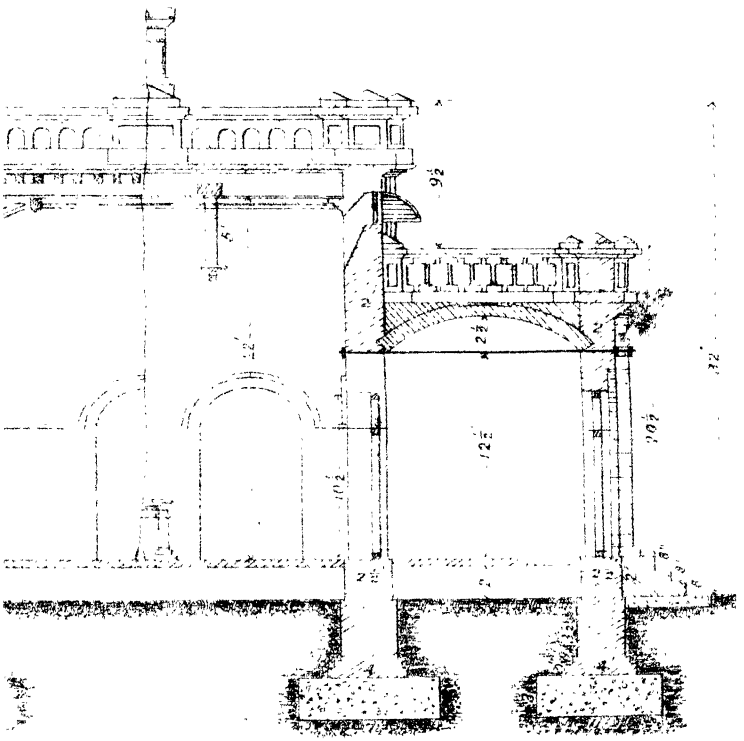
EDICAL SCHOOL FOR LAHORE.

Scale.—10 *feet* = 1 *inch.*

FRONT ELEVATION.







No. CCL.

ABSTRACT RETURNS OF THE RISE AND FALL OF THE RIVER GANGES AT BENARES AND MIRZAPUR DURING THE YEARS 1875 AND 1876.

N.B.—Zero of gauge at Benares is 196·80 above mean sea level, G. T. S. datum at Mirzapur 210·50.

		1875. Highest level above zero of gauge in the week ending				1876. Highest level above zero of gauge in the week ending			
		7th.	14th.	21st.	31st.	7th.	14th.	21st.	31st.
		ft. in	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
January,	Mirzapur,	3 11½ 3 10	3 8½ 4 0	3 5½ 3 10	3 4 3 5	0 0 0 0	0 0 0 0	0 0 0 0	2 2½ 1 9
February,	Benares, .. Mirzapur,	2 11 3 1	2 7½ 3 0	2 4 2 11	3 3 3 2	1 11½ 1 5	1 8 1 2	1 5 0 10	0 11½ 0 4
March,	Benares, .. Mirzapur,	3 11½ 4 2	3 11½ 4 5	3 7½ 4 1	2 11 3 4	0 9 0 2	0 6 0 0	0 5½ 0 3	0 0 0 0
April,	Benares, ..	2 0½ 2 5	1 6 1 11	1 0 2 3	0 9 1 10	0 1 0 11	0 0 0 8	0 0 1 2	0 0 1 6
May,	Benares, .. Mirzapur,	0 10 1 3	0 5 1 7	0 8 1 8	1 0 2 0	0 0 1 8	0 0 0 2	0 0 1 6	0 0 1 6
June,	Benares, .. Mirzapur,	0 7 1 4	0 9 2 0	1 1 2 3	11 6 9 8	0 3 1 7	0 2 0 7	0 3 0 10	2 1 1 10
July,	Benares, ..	10 8 11 2	19 0 20 3	28 0 28 11	38 9 40 6	6 0 8 7	20 2 20 6	30 6 31 5	30 10 33 10
August,	Benares, .. Mirzapur,	44 0 55 0	34 0 37 7	35 6 35 9	34 6 34 9	30 0 30 6	28 3 30 9	23 3 24 9	25 0 27 0
September,	Benares, .. Mirzapur,	21 10 22 3	31 6 32 10	33 0 33 7	33 7 33 5	24 7 26 0	30 11 32 3	26 0 28 6	21 11 20 0
October,	Benares, .. Mirzapur,	29 7 29 3	19 3 18 4	14 8 14 3	12 6 11 3	14 8 14 4	12 0 11 6	9 3 10 7	7 4 9 0
November,	Benares, .. Mirzapur,	10 1 9 0	9 0 8 0	7 11 6 9	7 0 6 1	5 11 5 4	1 11 6 2	4 2 6 3	3 0 4 8
December,	Benares, .. Mirzapur,	6 1 5 1	5 6 4 5	5 0 3 10	1 6 3 6	2 4 1 5	1 8 3 11	1 1 2 11	0 5 1 3

No. CCLI.

USE OF WROUGHT-IRON PIPES FOR THE WATER SUPPLY OF THE CITY OF SAN FRANCISCO, AND MINING TOWNS IN CALIFORNIA.

By J. Sheldon, Esq., *Exec. Engineer, Berar Irrigation.*

Owing to the perishable nature of wrought-iron sheet pipes, and to their not resisting corrosion when buried in the ground so well as cast-iron, it has not become a practice to use them for purposes of water supply; but, as it may not be generally known that they have been successfully used for the water supply of San Francisco and some Mining Towns in California, a few notes on the subject may be of interest to Engineers.

The following information regarding the water supply of San Francisco and the use of wrought-iron pipes, was given to me by Mr. H. Schussler, Chief Engineer, Spring Valley Water Works, San Francisco, during my visit to that city last year, and he showed me some of the wrought-iron pipes which had been laid, and in use for 12 years, and which appeared in perfect order.

Present supply of water from storage reservoirs 20 miles from San Francisco.

(*a*). Pilares Fos,.....reservoir contains 1,050 million gallons.
(*b*). San Andres,..... „ „ 6,500 „ „
(*c*). Crystal springs (upper), „ „ 8,000 „ „

Proposed future supply.

(*d*). Crystal spring (lower), reservoir contains 2,300 million gallons.
(*e*). Calaveras reservoir distance 50 miles, ... „ „ 40,000 „ „

Catchment of (*a*) and (*b*), 10 square miles.
„ (*c*) and (*d*), 29 „ „
„ (*e*), 140 „ „
with an extension of, ... 120 „ „

Present suppy is 12 million gallons daily.

Proposed for future supply (*a*, *b*, *c*, *d*, *e*, inclusive), 120 to 130 million gallons daily.

It is proposed for the future supply to construct a wrought-iron pipe 5 feet diameter, 22 miles in length, of $\frac{7}{16}$″ iron, for 600 feet head of water.

The following wrought-iron pipes have been laid and have been in use from 12 to 15 years, and are now as sound as when they were put down and quite free of rust, this result being due to the preservative coat of asphaltum and coal tar :—

Locality of wrought-iron pipes laid.	Length in miles	Diameter in inches	Thickness of iron	Rivets	Pressure or head of water in feet
San Andres to San Francisco,...	15	30″	$\frac{1}{4}$″	$\frac{3}{8}$″	340
Pol pipe,...	18	30″	No. 9	...	350
P : ocha pipe, ...	7	5″	$\frac{1}{16}$″	...	700
Cheroquee pipe,...	2½	30″	$\frac{3}{8}$″	$\frac{3}{4}$″	900
Virginia city pipe, ...	7	12″	$\frac{5}{16}$″	$\frac{5}{8}$″	1850
Lock's creek lode pipe,...	4	22	$\frac{1}{4}$″	...	300
Large Lock's creek lode, ...	feet 4700′	37″	$\frac{3}{16}$″	$\frac{3}{8}$″	300

The straight seams of the pipes are double, and the round seams single, rivetted and caulked.

The pipes were constructed in 26 feet lengths, each length being boiled for 15 minutes in a bath of asphaltum and coal tar at about 350° to 400°, Farenheit.

Pipes in ground 15 years are perfectly sound, inside and outside.

The cost of iron is 5 cents per lb., and for making, transport 20 miles, laying, dipping, &c., &c., 5 cents, or 10 cents total cost. This is about two-fifths to one-third cost of cast-iron pipes of same strength and diameter.

The advantage to be derived from using wrought instead of cast-iron pipes, is, on account of cheapness and facility of carriage, and especially in a country where cast-iron pipes are not readily obtainable, either on account of the difficulty of transport, or where a minimum first outlay is necessary, and which has been the case in California, where, an extraordinary high rate of interest has to be given for money. It is also known that wrought-iron will bear the pressure of a greater head of water than cast-iron.

There may be some cases where, either on the score of economy or for other reasons, wrought-iron pipes may be advantageously used in India.

BASSIM, WEST BERAR,
13th August, 1877. J. S.

No. CCLII.

NOTE ON THE CONSTRUCTION OF A MASONRY BAR ACROSS THE GANGES, AT THE HEADWORKS OF THE GANGES CANAL.

[*Vide* Plates I., II., III., IV. and V.]

By Capt. R. P. Tickell, R.E., *Exec. Engineer, Northern Division, Ganges Canal.*

The Ganges Canal takes its supply from the Ganges near Bhímgoda. At this point the river has five channels *i.e.*, the Dúdia, Níldára, Chiláwala, and New Channel, and the Main River. The head of the Dúdia channel is closed by a permanent bar which is only topped in high floods. The New Channel is entirely closed by a crib and boulder dam; and the river is allowed to run in the Main, Níldára and Chiláwala channels only.

A reference to *Plate* I. will show the positions of the various weirs and bands. It will be seen that they form a nearly continuous line, passing across the bed of the river from high land to high land; the Dúdia and Chiláwala weirs forming the two flanks. The only break is between Níldára and Chiláwala; but the nature of that part of the bed renders any protective works unnecessary for the present.

To supply the canal, bands are thrown across these channels, and the water is turned into what are known as Nos. 1, 2 and 3 supply channels. No. 1 band turns the main supply down No. 1 channel; No. 2 band turns the leakage which passes through No. 1 band down No. 2 channel; and No. 3 band catches any water that may pass through No. 2 band, and sends it down No. 3 channel. The latter band and channel are only used in cases of very great demand for water. These channels all unite above Hurdwar and form the Hurdwar supply channel, which runs down to Maiápúr. Here the required amount of water is passed

into the Ganges Canal through the Maiápúr regulator, and the surplus is allowed to escape through the Maiápúr dam. These arrangements are shown in *Plate* I.

The bands across the Níldára and Chiláwala channels are made of boulders. Those in the main river are constructed of cribs filled with boulders.

All these bands are carried away every rainy season, and have to be re-constructed during September and October. At this time of year there is a considerable discharge in the river, and consequently putting up the bands has always been a work of more or less difficulty. It was generally found too, that the river had, while in flood, scoured deep holes at one or more places along the proposed line of band; and these holes naturally added to the difficulties of construction, and sometimes caused delay in providing the canal supply.

Of late years, the increase in Canal irrigation made the demand for water so great, and so constant, that it became necessary to facilitate the construction of the bands by preventing the formation of these deep holes, and stopping any tendency there might be towards a retrogression of levels in the bed of the river.

To do this, it was determined to build a permanent bar across the river at the general level of the cold weather bed. This plan had been tried with success on the Níldára channel, and has since been carried out on the Chiláwala channel also. In the two latter cases, the bar was raised above the bed of the river, and it was found that the bed above the bar assumed an even surface level with the top of the bar. At this time the deep channel and main force of the river were on its left bank, and it was the unanimous opinion of the Canal Engineers that the river should be kept as much as possible on the right bank. It was, therefore, determined to commence the construction of the bar from the left bank in hopes of driving the river towards the right. A length of 300 feet was built in 1864, and had the expected result. This part of the work is shown as "Weir Complete" in *Plate* II. In 1874, the length of the bar had been increased to 590 feet; after the rains this length was found to be shingled up, and the force of the river passed beyond its right flank. In 1876, a further length of 290 feet was added making the total length of the bar, from its left flank, 880 feet. It now became evident that the limit to such extensions of the bar from the left only had been reached;

for the river was thrown with so much force on to the right bank, that the destruction of the island between No. 1 and 2 channels was threatened, and the laying of the cribs for No. 1 band was rendered very difficult. It was therefore determined that, before next rains, the bar must be completed across the Ganges, and that the nose of the island between Nos. 1 and 2 supply channels must be made strong enough to resist the full force of the river.

It was anticipated that the check placed on the scour by the construction of this bar might increase the action of the river elsewhere, especially down No. 1 supply channel. It was, therefore, determined to carry the bar over the island and across No. 1 supply channel; and protect the flanks of the bar by wing-walls. The general plan of the work is shown in *Plate* III. I will here give an outline of what has been done, and leave the description of the details to Lieut. Clibborn, the officer under whose immediate superintendence the work has been carried out.

It must be remembered that all the arrangements for carrying out this work were governed by the necessity of keeping up the required supply in the Ganges Canal.

Work was commenced at the end of the existing portion of the bar, (point *a*, in *Plates* III. and IV.,) and by the arrangements described by Lieut. Clibborn, the bar was carried completely across the Ganges and over No. 1 island. The down-stream wing-wall, and a portion of the Redan revetment were also built.

What had to be done now was to close and drain No. 1 supply channel, take the supply for the canal through or over No. 1 band, and divert it down supply channels Nos. 2 and 3. This was done by lowering 500 feet of No. 1 band, (*see* BI, *Plate* IV.,) and allowing the canal supply to pass over it, and making a strong crib and boulder dam across the head of No. 1 channel. When the water had settled itself down to this new regimen,—which it did most comfortably,—the left flank of No. 1 band was also lowered. The water passing over this flank ran into the river, and not into the supply channels; therefore this portion of the work acted as a waste weir (*see* IX., *Plate* IV.)

Hitherto the drainage operations had been attended by this advantage, that there was an ample outfall into the deep channel of the river below the work. But now the conditions were quite altered by the fact, that the canal supply must pass between the work and this outfall, while deep

drainage down No. 1 channel was impossible, because, the back water from Nos. 2 and 3 channels rose considerably above the foundation of the work. Two steam engines and several pumps were provided to get rid of the water, but it was more than doubtful whether they could do it. There was no alternative, but to make a tunnel from No. 1 supply channel, passing through the island, under the branch of the river carrying the canal supply, under the band which turned the supply down Nos. 2 and 3 channels, and discharging into the deep channel through an old crib and boulder bar, known as "Login's weir." With the assistance of this tunnel the bar across No. 1 supply channel was laid with the exception of a gap, which it was necessary to leave when the demand for water in the canal arose in July.

In order to fill in this gap, with a running canal, all the difficult, expensive, and I may say dangerous, operations of last year would have to be repeated. The demand for irrigation is now so constant, at nearly all seasons, that there seems no probability of a canal closure long enough to allow the work to be done during it.

The fall in the bed of river is so much greater that of the supply channel, that I do not fear any scour down the latter. I have therefore proposed that we should content ourselves with having some concrete blocks ready to throw into the gap if any action sets in.

This year's floods were so slight that the work cannot be said to have undergone the test of an average rainy season; but from what was seen this year, there is every reason to hope that it will be quite successful.

R. P. T.

Description of the Construction of No. 3 Bhimgoda Weir. *By* LIEUT. CLIBBORN, B.S.C.

The chief difficulty met with in the construction of this work was the management of the water, including the diversion or passing off of floods, freeing foundations from water, and keeping up the canal supply.

Before explaining how the difficulties connected with water were contended with, it is necessary to describe the different classes of bands used at the Ganges Canal headworks. No clay being available within any reasonable distance, fine shingle and sand have to by used to make the bands water tight. Plain shingle bands are used in situations where there is little or no current, and no great depth in the water; and boulder or crib

bands in places where the run is moderate or very strong, and the depth considerable; sketches of each class of band are given in *Figs.* 1, 2 and 3, *Plate* V., and it will be noticed that a mat of grass or fine branches woven together is used to catch the small shingle and prevent percolation. This mat should be carried at least 10 feet on the ground at the toe of the band.

The leakage almost invariably comes out at the point marked A, and it is found that if the mat be kept well on the ground in front of the band the percolation is much less.

Fig. 3, *Plate* V., is the cross-section of the bund used for Nos. 1 and 2 supply channels. Each crib is something over 10 feet wide, (eight cribs make 100 running feet of band,) and after having been put together on a sloping foreshore of the river is taken up by a boat, fitted with shear legs, winch, and capstan. It is attached to the shear legs of the boat by a suspending rope, fastened at B, *Fig.* 3, *Plate* V. To balance the weight of the crib, which hangs over the stern of the boat, the bows are loaded down with a number of large boulders, which are afterwards used to weight the crib down when in position. The boat is conveyed by means of a snatch block, working on a cable stretched across the river, to a point just above the position the crib is to occupy in the bund. The crib is then fastened by ropes to the one previously laid, and also in such a manner to the boat, that it cannot be twisted by the current; and, as it is lowered, is gradually pulled into position, and filled with boulders from a number of small boats fastened to the large boat, which is kept in its proper place by a rope wound round the capstan, and fastened to the snatch block which runs along the main cable.

This block can be moved into any required position by means of small capstan placed on each bank. As the crib is sometimes carried away by the stream before being properly weighted, arrangements are made to allow of its being instantly cut adrift, if necessary. Each crib is only loaded at first with as many boulders as will keep it firmly in its place. The filling is commenced when the whole line is laid and is carried on, so that the depth of water flowing over all parts of the band shall be uniform. When the filling of the cribs with boulders is complete, the mats and shingle are added.

In all the diversions and drains, &c., some one of three classes of bands was used, nearly 2,500 running feet of crib band alone were put in. On commencing work at the point *a*, in December 1876, a drain was dug

into the channel YZ, (see *Plate* IV.,) and a length of about 150 feet of the foundations of the weir was enclosed by shingle bands.

The drain reduced the depth of water on the foundation level to about 2·5 feet; and the shingle having been excavated out to a depth of 1·5 feet, the square cribs, forming the framing of the weir, were countersunk into their places the remaining foot; and, one by one, filled with masonry, composed of boulders laid in equal parts of stone lime, surkhí, and coarse clean shingle. About 60 cubic feet of this mortar is required for 100 cubic feet of work. With the exception of about the first 100 foot length built, the upper foot of masonry was laid in mortar composed of 30 cubic feet of kankar lime, and 30 cubic feet of shingle to the 100 cubic feet of masonry. The kankar lime was of superior quality burned with coal and charcoal at the Jaoli Falls, (50th mile of the main canal,) and ground very fine with revolving pan mortar mills worked by a 40 H.-P. Turbine. The lime was boated up in grain bags, and cost about Rs. 30 per 100 cubic feet delivered at site. Boulder masonry costs Rs. 2-8 for labour per 100 cubic feet, which includes the collection of the shingle and boulders. Thus the total cost of the masonry may be estimated at from Rs. 12 to 14 per 100 cubic feet, including lime. Kankar lime, which is eminently hydraulic, was used for the upper foot of masonry on account of the necessity of running water over each section of the work as soon as it was completed. The next 200 feet in length were built in precisely the same manner, except that the work was much delayed by constant floods in Feburary 1877. The temporary bands were several times breached, and the original drain so silted up that it was determined to utilize it as a bywash to carry the surplus leakage from No. 1 band into the river, and to run the temporary bands right up to the Island between Nos. 1 and 2 channels. The abnormally high state of the supply in the river rendered this possible, as the leakage through No. 1 band was not required to keep up the supply for the canal. A reference to *Plate* IV. will show the state of the work at this time. The temporary bands ran along the line DCEG. The leakage from No. 1 band passed through YG, and a new drain WJL, was dug along the face line of foundations. This drain was 15 feet wide, and was cut through Login's weir (OL); but the leakage through the band was so heavy, owing to the great head of water on it, (from 12 feet to 15 feet,) that the drain only lowered the surface to 5 feet above foundations. As it was impossible to work in this depth of water, a second band was

then made along the toe of DCEG, forming a high level drain to carry off a portion of the leakage. This drain was carried over the low level drain by a wooden aqueduct, 10 feet wide and 20 feet span at J. A permanent sál-wood tunnel fitted with sluices was built under the weir at S, not only to carry off drainage from up-stream of the weir, but to act as a main drain in case of any future works north of the present weir. By the aid of these arrangements the crib and masonry work was connected with the Redan Island, and the Lower River wing-wall, and 100 feet of the Redan revetment built. There was however great delay and inconvenience from continued rain and floods. After many minor disasters, an extraordinary flood came down the river on the 21st of March, passed almost completely over No. 1 supply band, and washing away a great part of the temporary bands—silted up all the drains and excavations, and carried away the aqueduct and a good deal of collected material. The river, however, appeared to be satisfied after this, and did not give us any great trouble afterwards until the regular snow water floods came down.

The details of the Redan revetment are shown in *Fig.* 5, *Plate* III. The frames were put together close to the work, and the poles nailed on after the foundations were built in. The revetment was made continuous, not in seperate cribs, as there was but little danger of settlement. The main timbers are fastened with one-inch screwed bolts and 12-inch twisted nails; and the poles with eight-inch plain nails: twisted nails weigh about one seer each and have a very strong hold in sál-wood: eight-inch nails run about 160 to the maund. The square boxes and revetment cribs are also bolted together at A. *(Fig.* 5, *Plate* III*).*

The system of double or treble bands and drains at different levels, referred to above, appears to be almost the only way of lessening leakage where you have to overcome a heavy head of water with a bad sub-stratum to found the band upon. The leakage, as pointed out before, does not pass *through* the band, but *under* it. All along this portion of the work there had been heavy scour, and consequently, a deep hole during the floods, and when No. 1 band was under construction, the deep holes had become loosely shingled up; if the temporary band could have been built across this under a heavy scour, each crib would have sunk down to the solid bottom, and we would have had comparatively little trouble with drainage, but this was not practicable, owing to the necessity of keeping up the canal supply.

This portion of the work was completed and the diversion commenced on the 1st of May. In the mean time the arrangements for draining the foundations of the Redan revetment and the weir across No. 1 supply channel were made. Fortunately for our purpose, but unfortunately for himself, Mr. Wilson, the enterprising contractor for State Railway sleepers, had floated down the river a large number of 10′ × 10″ × 5″ deodar sleepers, and some of these got broken on the way. The available four feet and five feet lengths were cut in two and used to construct a tunnel (XZ, *Fig.* 1, *Plate* VIII., and *Fig.* 4, *Plate* X.), passing completely under the proposed diversion of the canal supply. Owing to the difficulty and expense of excavation below spring level, the top of the tunnel was 15 inches above the normal bed of the river at the line of crossing; so that when covered with a protecting layer of boulders it acted somewhat as a submerged weir, and during floods the action over it was sometimes very heavy. But it never moved in any way until the 3rd of July, when the regular rain floods breached No. 3 temporary band, and carried away some of the tunnel along with the crib immediately over it. The section of the tunnel being 5′ × 4′, and deodar wood very light, its buoyancy may be said to equal 1,200 lbs. per foot run, requiring 15 cubic feet of boulders per foot run at least to give it sufficient stability. It was not however possible to put more than three or four cubic feet above it, so the section was made somewhat broader at the base than the top, and loaded cribs, braced across, were put on each side at 30 foot intervals, a continuous beam was also bolted along the outside one foot above the bottom, and this was loaded down as shown in *Fig.* 4, *Plate* X., *aa*, being three feet lengths of engine firewood, laid one end resting on the beam and the other on the solid ground. During flood there was a depth of from eight feet to nine feet of water passing over the tunnel, and the fall over it was very perceptable. Its having stood firm with so small a factor of safety shows, I think, that provided a weir is protected from scour above and below a very slight section will suffice. During the progress of the work in No. 1 channel, the interior was daily inspected by a *beldár* passing completely under the river, and the leakage through the joints was found to be very slight; the caulking with the pounded root of the *dhák* tree (nassa dhák) being efficient. *The total* cost, including laying, &c., was Rs. 4 per foot run, or nearly 2,800 Rs. altogether.

The diversion of the Canal supply was commenced early in May. Nos. 2 and 3 channels having been previously excavated to a width of 200

feet and 100 feet, respectively, and the band 1YGLKO, *Plate* IV., built, with the exception of the parts shown in shading through which drainage passed. The bands MN and EG, &c., were cleared away, drains, &c., filled with boulders, all the vacant spaces in IO were closed up, and FSE and CB built, the laying of the cribs for AB, the canal band, was commenced. This part of the work, and indeed the whole process of the diversion, was much inconvenienced by constant floods. The canal supply, estimated at 7,000 cubic feet per second, was taken over No. 1 band at BI, in a length of 500 feet portions at B and I, being left to act as spurs. It was not possible to take out the entire band, nor in any way advisable; because, the channel below being deep, but unavoidably narrow at MO, it could not carry more than 10,000 cubic feet comfortably, (it eventually carried nearly 14,000 cubic feet, but there was great danger all the time.) Provision was therefore made to divert surplus flood water across the left flank (IX) acting as a waste weir. Towards the close of the work, the river had risen so much that the whole of No. 1 band, to the left of B, was cut away. The water also passed over the Island 1Y, the band 1Y having been removed. It will be understood that the band from Y to O was in very heavy embankment, and any breach in it would have passed the whole canal supply down the river, the entrance to Nos. 2 and 3 channels being at a higher level than the river bed.

On the 4th of May, the lowering of No. 1 band was commenced by digging a hole in the shingle in front of No. 1 band at each *balla*, and cutting off the front members of the cribs, three feet below water surface, the holes were then refilled, and the outside logs or *ballas* cut off at lower water surface. This enabled us to remove all the woodwork without disturbing the boulder filling, which was done on the 6th May, leaving the band in the state shown in *Fig.* 5, *Plate* V. The mats and shingle which were so cemented by silt, &c., obtained from the water percolating through them, that they stood in the position shown, were cut away the same day, and the band at AB completed by the 12th May.

The remainder of the work was carried out in a similar manner to that before described. The main leakage was taken down No. 1 channel, other leakage in a lower level channel connected with the tunnel, and the foundations then pumped out.

Two eight-inch centrifugal pumps and a 12-feet diameter scoopwheel, worked by two 12 H-P. engines, were used. The centrifugal pumps were

worked together by means of a counter shaft, and the lift being low did fairly satisfactory work; but pulling engines about over boulders does not improve them. The scoopwheel is a very good form of pump for a low lift, the draw into it is so great that boulders are apt sometimes to injure the fans but that can be obviated by passing the water through a screen. It discharged 11 cubic feet (measured) per second with a six foot lift.

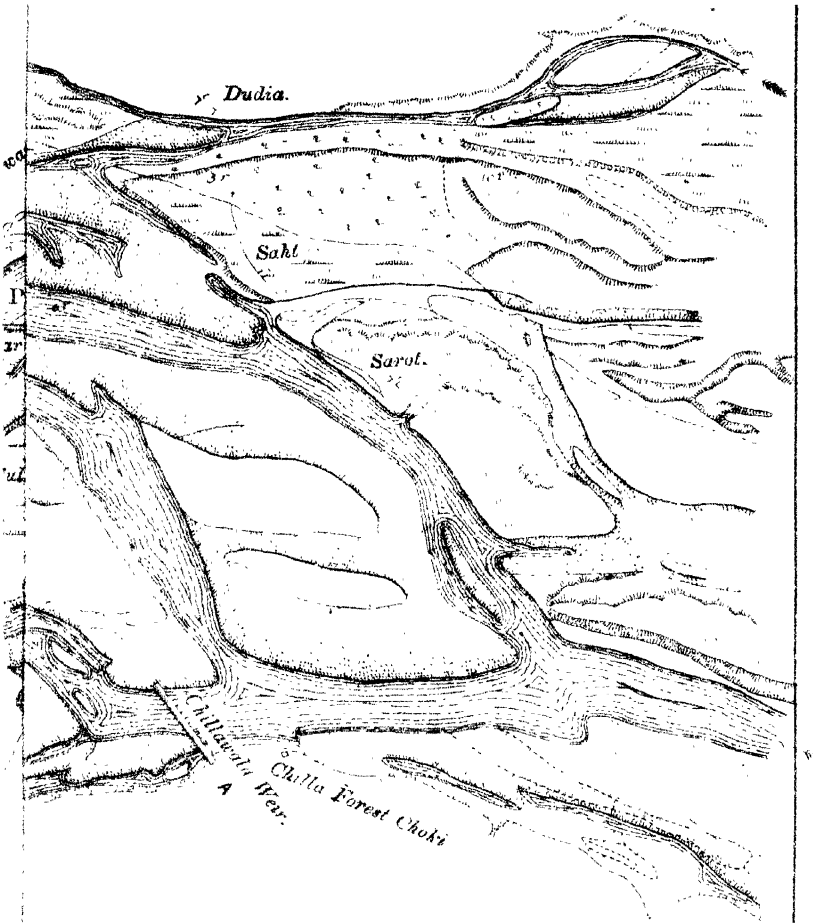
The greatest trouble was met with at the nose of the Redan. It was with the greatest difficulty the cribs were got in; and it being found impossible to get them down the full depth, they were left one foot higher than the rest of the work. The crib work at this point is rather complicated, ending in a log of sál wood 40′ long × 1′ square, the lower end of which is firmly braced to five voussoir shaped cribs in the form of an arch, which are completely filled with kankar lime masonry. As the floods were daily expected down when this part of the work was nearly completed, 50 feet of the masonry revetment was planked over and strengthened with strips of iron screwed on.

The light poles or "tors" shown outside the masonry of the Revetment, (*a*, *a*, *Fig.* 5, *Plate* VIII.,) are merely to protect the work whilst green, and they will be removed and the masonry plastered when thoroughly hard.

Abstract of Estimate for Completing No. 3 Retaining Weir, Bhimgoda.

	Quantity	PRICE		Amount	Total
		Rate	Per		
		RS.		RS.	RS.
Excavation, ...	10,06,910	9-0	%₀₀ c.f	9,062	
Shingle bands, ...	5,17,600	5-0	%₀₀ „	2,588	
Boulder „	62,720	10-0	%₀₀ „	627	
Do. filling, ...	2,21,250	8-0	%₀₀ „	1,770	
Kokat cribs band, ...	1,800	614-0	% l. ft	11,052	
Square cribs, (10′ × 10′ × 5′,) ..	613	30-0	each.	18,390	
„ (10′ × 12′ × 5′,) ..	5	34-0	„	170	
Oblong cribs, (10′ × 5′ × 5′,) ..	95	26-8	„	2,518	
Trapezoidal cribs, ...	95	68-0	„	6,460	
Sál wood, ...	75	3-0	feet.	225	
Boulder and stone lime masonry, ..	2,16,600	13-0	% c.ft	28,158	
Boulder and kankar lime masonry, ..	65,000	14-8	% „	9,425	
Earthwork, ...	1,96,200	3-0	%₀ „	589	
Pumping, ...	50	25-0	day.	1,250	
Maintenance during and repairs after floods, ...	..	..	..	5,000	97,284
Add, say 10 per cent. for Contingencies, ...					9,728
Grand Total, Rupees, ..					1,07,012

J. C.


Dudia.
Sahl
Sarol.
Chillawala Wer.
Chilla Forest Chokı
W
H
A
L

No. 1 Supply Channel
No. 2 Supply Channel
No. 3 Supply Channel
No. 3 Bank
No. 3 Bank
Drain
No. 3 Weir
No. 1
No. 1 Weir

FIG 3.

DUDIA WEIR

Scale—12 feet = 1 inch

400 *feet long*

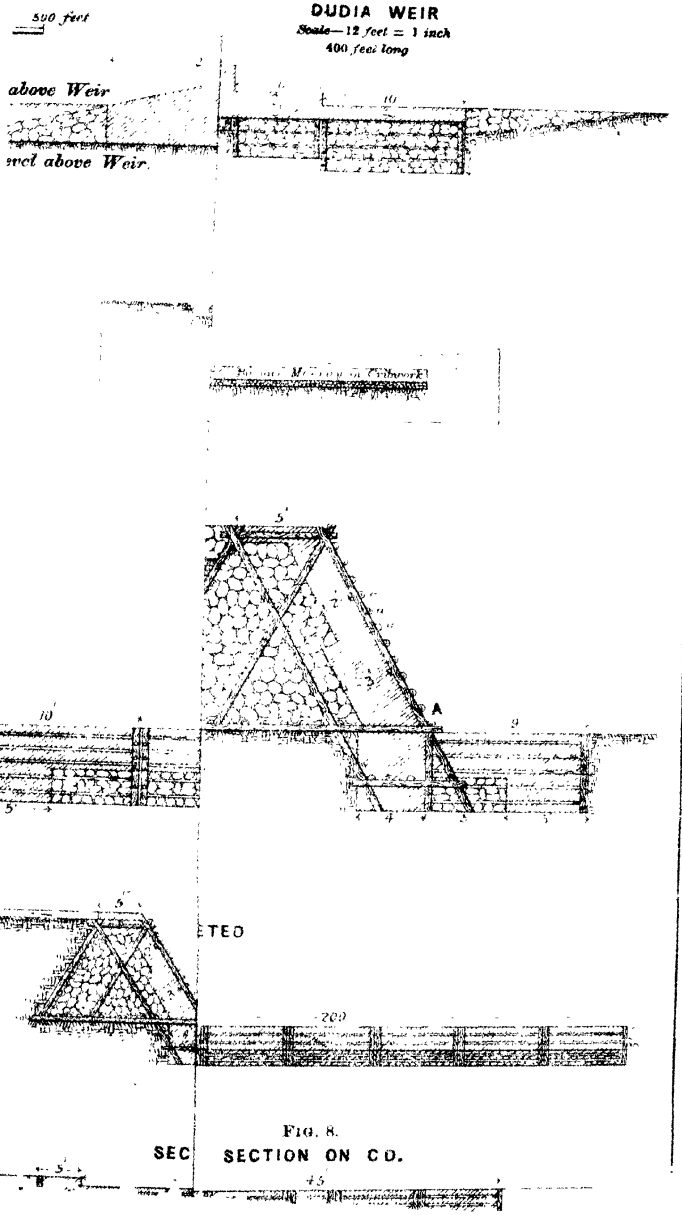


FIG. 8.

SEC SECTION ON CD.

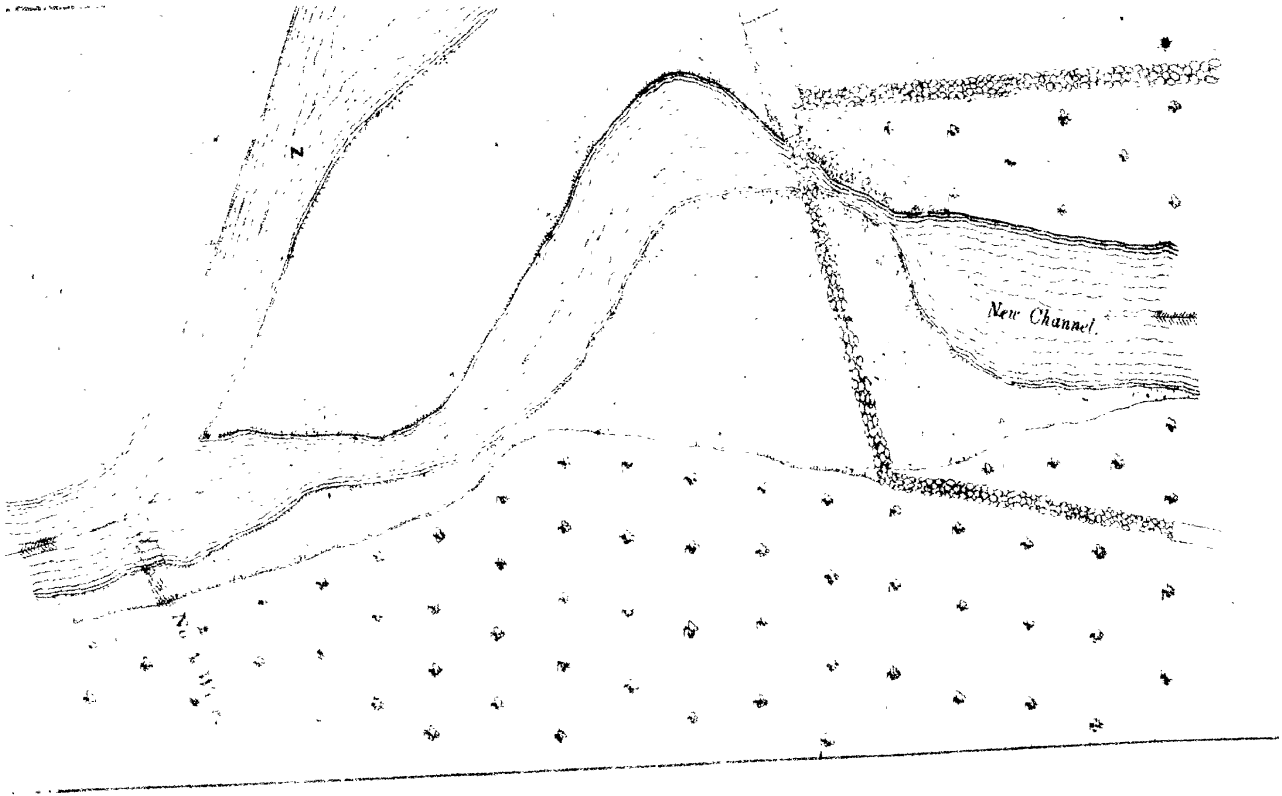

N
New Channel

FIG. 1.

Scale.—10 *feet* = 1 *inch.*

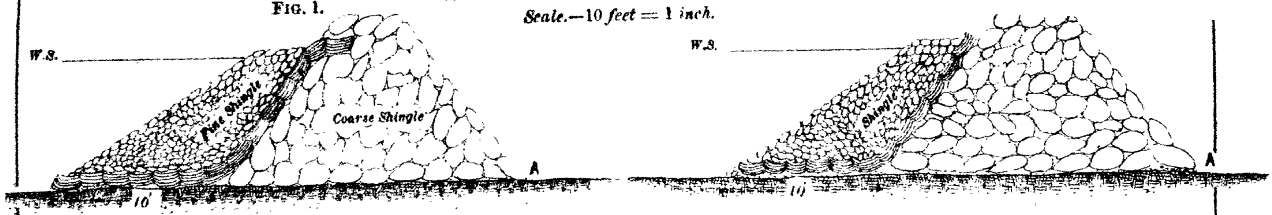


FIG. 3.

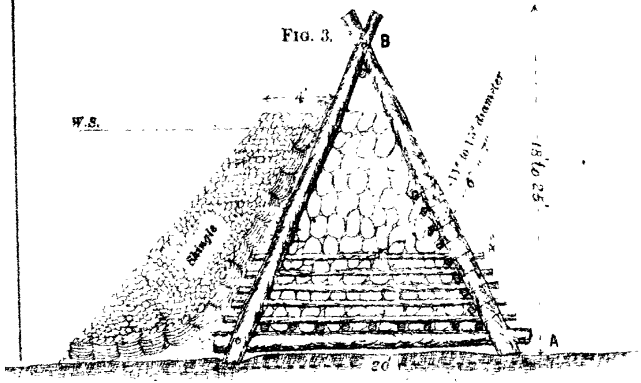


FIG. 4.

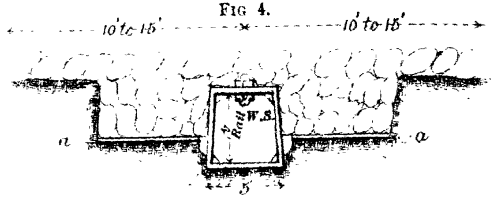


FIG. 5.

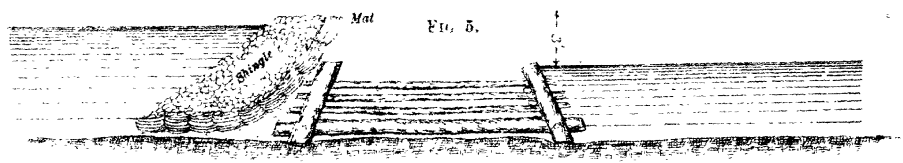


PLATE V.

No. CCLIII.

ABSTRACT RETURNS OF THE RISE AND FALL OF THE RIVER GOGRA AT BAKHARIA IN PARGANA NATHUPUR, AZAMGARH DISTRICT, DURING THE YEARS 1875 AND 1876.

The gauge has been erected on the Gogra bund, and the zero of gauge, which is on a level with the formation level of the bund, has been found by calculation in connection with G. T. S., Station No. 153, (Sec. VII.,) to be 221·32 feet above mean sea level at Karachi.

Months.	Highest water-level above mean sea level.				Depth of highest water level below zero of gauge.			
	7th.	14th.	21st.	30th or 31st	7th.	14th.	21st.	30th or 31st.
				1875.	ft. in.	ft. in.	ft. in.	ft. in.
July, ...	210·07	211·74	210·65	213·49	11 3	9 7	10 8	7 10
August, ...	214·82	214·57	212·74	216·32	6 6	6 9	8 7	5 0
September.	213·40	212·99	211·82	211·40	7 11	8 4	9 6	9 11
October, ...	209·5	207·57	206·57	205·57	12 2	13 9	14 9	15 9
November, ...	204·90	204·32	203·74		16 5	17 0	17 7	
				1876.				
August, ...	214·16	214·49	215·49	214·07	7 2	6 10	5 10	7 3
September, ...	212·57	212·82	212·32	215·32	8 9	8 6	9 0	6 0
October, ...	212·91	211·49	209·91	208·16	8 5	9 10	11 3	13 2
November, ...	207·41	206·82	206·24	205·57	13 11	14 6	15 1	15 9
December, ...	205·24	205·00	204·74	204·59	16 1	16·4	16 7	16 9½

No. CCLIV.

NOTE ON NEW RESERVOIRS FOR NEW YORK.

[Written in 1869].

By Major J. M. Heywood, R.E., *Exec. Engineer, Bengal Irrigation Department.*

Reservoir at Boyd's Corner.

This reservoir, now under construction, is intended to store up a supplementary supply of water for the town of New York. It is situated at Boyd's Corner, 23·75 miles above the Croton Lake in a wild, bleak, hilly country, which is exposed to a rainfall similar to that experienced in New York. This amounted in 1867 to 50·07 inches, that in New York having been 50·33 inches. A curious phenomenon is here observed, which has often been noticed in other localities, viz., the extreme partiality of rain to certain spots, thus at Sing-Sing, 7½ miles below the Croton Lake, the rainfall in 1867 amounted to 88·02 inches, and in 1868 to 93·42 inches, whilst at Tarringtown, situated 6 miles to the south, the quantities gauged were respectively 45·73 and 55·19 inches, and in the hills at Boyd's Corner, 50·07 and 50·33 inches.

The dam is to be 75 feet at its highest point, measured from the lowest depth of the foundation, this will suffice to pond back the water a distance of 7,500 feet, and flood an area of 303 acres. The quantity thus stored is calculated to be equal to 431,290,000 cubic feet. The drainage area is 20·37 square miles.

The foundations of the dam are laid on the solid rock, all loose, soft, or broken rock having been carefully removed. Nearly the whole of the foundations are of concrete, the exception being a length of about 225

feet under the outer face wall on the north-easterly end, where cut stone masonry has been substituted.

The superstructure is now (1869) under construction, it consists of two outside walls of cut stone left rough on the faces, and filled in with concrete and large stones. The concrete is formed of the gneiss and granite rock found in the vicinity, broken so that the maximum dimension shall not exceed two inches, and the minimum one-fourth of an inch, mixed with mortar previously prepared. The mortar is made from Rosendale cement mixed with sand, in the proportion of 1 part of cement (packed) to 2 of sand (loose), this makes 2·4 parts of mortar, the shrinkage being one-fifth ; 4·8 parts of loose stone are added, which reduces to 2·5 parts, if the interstices are deducted, so that a cubic yard of concrete requires

	5·5	cubic feet of Rosendale cement.
	11·0	„ „ „ loose sand.
	26·4	„ „ „ broken stone.
Total, ...	42·9	cubic feet.

The stone weighs	167	lbs. per cubic foot (solid).
„ cement	71	„ „ „ „ (packed).
„ sand	83	„ „ „ „ (loose).

The large stones in the interior of the dam are on an average five feet long and two square feet in section. They are laid in layers, alternately parallel, and at right angles to the outer walls of the dam. Each stone is well bedded in and covered with mortar, and then packed up with cement.

The facing stones are never less than three feet by two-and-a-half feet by one foot, and are dressed for at least a foot of their length, so that the joints in that distance shall not exceed three-fourths of an inch. Headers, two feet by four feet by one foot, and upwards, are inserted at every three feet in height, and every six feet measured on the line of the dam.

At the north-east extremity, two canals or outlet culverts, four feet three inches in diameter, are made through the mass of the masonry at a depth below the crest of 57 feet : they empty into the river below.

The machinery for regulating the flow will be worked in a small gate-house, sixteen feet by nine-and-a-half feet, built immediately above the outlet on the down-stream side. The walls of the gate-house are to be of stone, lined inside with brick masonry; the latter material is also to

) employed in the roof, which will be one foot thick, filled in at the)andrills with concrete, and covered with blue stone flagging three inches ıick.

In plan the dam is right lined, the curved form, nearly always adopt-ł in similar work in Europe, not having been considered necessary.

In profile the inner face is carried up vertical, and the outer with a atter of $2\frac{1}{2}$ to 1. The crown is 9·8 feet broad. The waste weir ⁄ill probably be cut in the hill side on one of the flanks, but its exact)osition has not yet been definitely fixed. The following profiles show ıt a glance the difference between the American and French types of such work.

1*st*. Where the latter is intended for broad gorges (limit pressure 85·3 lbs. per square inch).

Sectional area of American type,

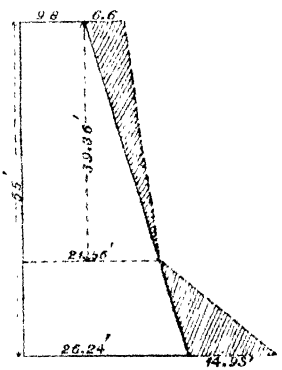
$$\frac{9{\cdot}8 + 26{\cdot}24}{2} \times 55 = 991{\cdot}1 \text{ square feet.}$$

Sectional area of French type,

$$\frac{16{\cdot}4 + 21{\cdot}35}{2} \quad 3 = 743{\cdot}92$$

$$\frac{21{\cdot}35 + 41{\cdot}17}{2} \times 15{\cdot}64 = 488{\cdot}90$$

$$\text{Total} = 1232{\cdot}82 \text{ sq. ft.}$$



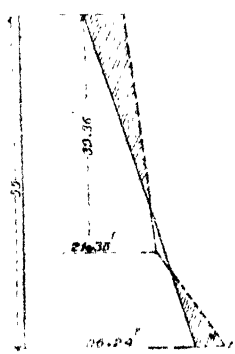
2*nd*. Where the French type is intended for narrow gorges, the limit pressure remaining the same as before.

Sectional area of American type = 991·1 square feet.
Sectionalarea of French type,

$$\frac{16{\cdot}4 + 21{\cdot}35}{2} \times 39{\cdot}36 = 743{\cdot}92$$

$$\frac{21{\cdot}35 + 32{\cdot}67}{2} \times 15{\cdot}64 = 422{\cdot}43$$

$$\text{Total} = 1166{\cdot}35 \text{ sq. ft,}$$



3rd. Where the French type is intended for both kinds of gorges, but the limit pressure is increased to 199 lbs. per square inch.

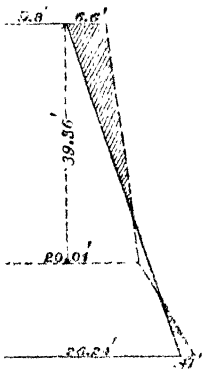
American type = 991 square feet.

Sectional area of French type.

$$\frac{16{\cdot}4 + 20{\cdot}01}{2} \times 39{\cdot}36 = 716{\cdot}55$$

$$\frac{20{\cdot}01 + 26{\cdot}71}{2} \times 15{\cdot}64 = 365{\cdot}35$$

Total = 1081·9 sq. ft.



High Service Reservoir at Carmansville.

The High Service Reservoir is another of the works rendered necessary by the rapid increase in the town of New York, it is so designed as to allow of the water being forced up by gravitation to the higher points of the suburbs.

The banks are being constructed of earth with a puddle wall in the middle. The inner and outer slopes of the banks are all of $1\frac{1}{2}$ base to 1 perpendicular. The inner or water slopes are covered with a stone pavement one-and-a-half feet thick, the outer slopes are covered with soil one foot thick. The banks, when finished, are to be nine feet six inches at the top, and are to rise two feet above the water line. The puddle bank will extend from the rock to within two feet of the top of the bank. It is to be four feet wide at top in the bank, and 10 feet wide at a plane 18 feet below the top of the reservoir bank, so that the sides above that height approach each other with slopes of $2\frac{1}{4}$ inches base to 1 foot vertical on each side.

The specifications lay down that the earth to be used both in the puddle trenches and embankments must be free of all stones more than two inches in any dimensions. The embankments are to be formed in layers of not more than six inches, well packed, by carting, rolling or ramming: they are not to be carried up more than two feet in advance of the puddle.

The paving of the interior slopes, 18 inches in thickness, is to consist of a single course of stones, set on edge, at right angles with the slope and laid in cement mortar. The concretes is to be formed of clean broken stone which will pass through a $1\frac{1}{2}$ inch ring, mixed with cement mortar. This mortar is to be composed of 2 parts of sand to 1 of cement. The cement is that known as Rosendale or Newark. The proportions of the mortar and stone in the concretes depend on the capacity of the stone to receive the mortar, and are determined by the Engineer accordingly.

The interior wall is made perpendicular for two feet in height at the top and two feet thick: it is to be capped with a granite coping one foot by three feet.

The bottom of the reservoir is to be covered six inches deep with good

to be two gate-houses, one 27 feet 2 inches × 27 feet; the other 27 feet × 35 feet 8 inches.

The water is to be pumped up from the aqueducts below by a powerful steam engine, of the kind known as Worthington's Duplex Pumping

This engine is very extensively used in the United States, and is stated to give very good results, and to be economical in the consumption of fuel; it also requires less attention from skillful enginemen than any other kind now in use. It is strictly a steam pump, consisting of two steam cylinders and two water cylinders laid horizontally in pairs, the piston rod of each steam cylinder extending to its water cylinder, and working a water displacement plunger. The connecting rod of the right hand engine works the steam valves and air pump of the left hand engine, and *vice versâ*. A pair of engines similar to those recently constructed at Charlestown, Salem and Newark is capable of elevating 5,000,000 gallons of water per 24 hours.

J. M. H.

No. CCLV.

BRUSHWOOD MATTRESSES FOR RIVER-TRAINING WORKS.

By Capt. R. P. Tickell, R.E., *Exec. Engineer, Northern Division, Ganges Canal.*

Brushwood mattresses, similar to those so extensively used in Holland, have been found very successful as spurs for training the hill torrents crossing the upper part of the Ganges Canal.

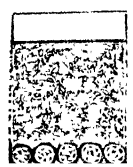
The branches obtained by trimming the trees, chiefly shísham, on the Canal banks, have been used for making the mattresses; but the best material would be Mulberry, Willow or Málá (Vitex trifolia). As river training works, once begun, generally go on for several years, there would seldom be much difficulty in arranging for a supply of brushwood.

The mattress consists of brushwood contained between two layers of fascines, and is constructed as follows:—

Plan of 1st layer. *Plan of 2nd layer.* *Cross Section of Mattress.*







Brushwood.

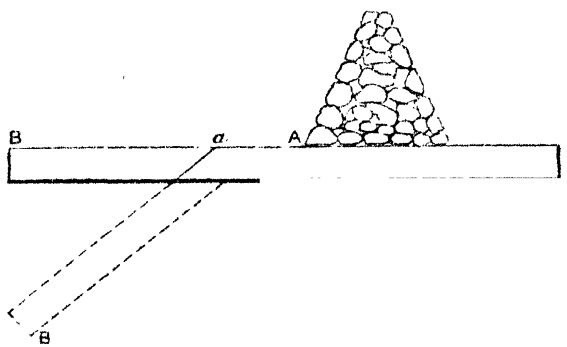
Lay a row of fascines of the required width, each fascine being of the full length of the spur. Then drive bambús or stakes into each fascine

at intervals of 2 feet, and to each stake tie the end of a rope, the other end of which is attached to the fascine. On the bed of fascines thus formed lay brushwood 3 to 5 feet thick, and on it lay another row of fascines similar to the former one, but at right angles to it. In this case each fascine will be of the full *width* of the spur.

Now pull up the bambús that were driven into the lower layer, and they will bring up with them the end of the rope attached to them. Bind this end round the fascines of the upper layer. The other end of the rope being attached to the lower layer, the whole will be thoroughly bound together, and the brushwood will be well compressed between the two layers of fascines. Of course the fascines forming each layer are firmly bound to each other.

In Holland these mattresses are used as foundations for piers, breakwaters, &c., and are laid as follows :—

The edges of the mattresses are attached to boats filled with stones, and the mattress is floated over the place where it is required to be sunk. The crews of all the boats commence to throw the stones from their boats on to the mattress, and continue until the mattress nearly becomes so heavy, that the boats can support it no longer. Then, at a given signal all the ropes attaching the mattress to the boats are cut at once, and the loaded mattress sinks into its place. More stones are then thrown into it, until the required foundation is obtained. The mattress must be considerably wider than the base of the foundation. One of the great advantages of the mattress is its flexibility, which enables it to adapt itself to



inequalities of the bed on which it is laid, and also to assume a position

favourable to checking scour; thus if there were a scour along the toe A, the mattress AB would assume the position AαB′, and form a good protection against it.

It may seem that brushwood is a perishable material to form the foundation of permanent works; but it is assumed that, as the brushwood rots, its place is take by sand, drift, &c. As a matter of fact settlement does not take place. The facility with which mattresses assume a position to check scour make them very suitable for laying in places where a river has made a dead set on to its bank. For such work, and training hill rivers, the matresses will generally be laid dry. It is not always possible to obtain heavy material for loading the mattresses at a reasonable cost. Sand bags filled with earth and firmly bound to each other will answer the purpose very well. In one case a flood came down on a mattress which was not only unloaded, but unprovided with the upper layer of fascines; the mattress stood, threw up a heavy silt deposit, and diverted the flood. This has led to a number of spurs being made of unloaded mattresses, which have stood well: but it would be premature to assume that unloaded mattresses can, as a rule, be depended upon.

When first using mattresses, there is a temptation to try and assist them by piling along their edges, driving stakes through them, &c. This must be resisted, as it deprives them of their great source of strength, *i. e.*, their flexibility. With brushwood brought from a mean distance of $2\frac{1}{2}$ miles, the mattresses have been made for Rs. 6 to Rs. 8 per 1,000 cubic feet, including everything. It is by no means certain, as yet, that this is the proper rate.

R. P. T.

No. CCLVI.

NOTE ON INCLINED GAUGES FOR MEASURING THE HEIGHT OF WATER IN RIVERS AND CANALS.

[*Vide* Plate I.]

By E. A. Parsick, Esq., C.E., F.G.S., *Asst. Engineer.*

In India, where rivers abound subject to heavy periodical inundations, it is often of the greatest importance, in connection with canal, embankment, and other schemes, to ascertain the maximum and minimum heights of floods, and also their oscillations between these limits, at obligatory points, whose loci, though depending chiefly on the nature of the project, should also be selected as far as possible.

1*st.* Where the bank is firm, is not under erosive action, and has a uniform minimum slope.

2*nd.* Where sandbanks, islands, eddies, and other causes likely to disturb the normal conditions of flow do not exist.

3*rd.* Where sufficiently low readings can be taken.

Each site selected should also be suitable for measuring the quantity of water passing through the river-section opposite the gauge, as it is of the utmost importance to record the slightest variations in hydraulic height, while discharges are being taken.

Sites conforming to all the above requirements will seldom be found, as owing to the generally tortuous course of most Indian rivers, few, if any, sufficiently long reaches, meeting the most favourable conditions of either gauge-readings or discharges, exist; and the most therefore that can be expected is a selection of points, at which causes likely to affect injuriously the observations proposed are reduced to a minimum.

Such sites, within admissible distances of the obligatory ones will always be found along a length (*ab*), *see Fig.* 1, *Plate* I., between adjacent river bends, above which the acceleration caused by the upper bend (A) has ceased, and below which the afflux and consequent retardation resulting from the lower bend (B) commences.

It is evident that a gauge placed as indicated, *i.e.*, between the points *ab*, will record river heights, and will not be so liable to accidents as one situated in either the length *a*A or *b*B, and that the nearer the gauge is to the lower bend B, within the length *ab*, the better will all requirement be met is also evident, for thus a maximum length of base line *cd* will be secured, and the "run" for timing velocities, will also be located within the limit, where disturbing causes are at a minimum.

It may here be casually noticed, that though 50 feet was the standard run adopted for the most critical of the Mississippi experiments, and that though the same length was found most suitable for the more recent experiments at Roorkee, yet that in all cases, where time is not recorded by other than ordinary pocket watches, the safest run will probably be 100 feet in connection with the fact that the chances of error in deducing velocities, and the chances of floats diverging from parallelism to the axis of the stream are inversely as the length of run.

As regards the relative merits of vertical, and inclined, gauges, it may safely be stated that the former are best suited for measuring the height of cross-country inundations; while the latter, for the following reasons, will be found more useful and economical along river and canal slopes:—

1*st.* The dimensions of each decimal graduation permit of approximate readings to hundreths, and this combined with the size of the figures, and the fact that the observer can walk down to the point to be recorded, reduces the chances of error in reading to a minimum: thus, in the example given farther on, the area of each tenth of a foot is 0·251 × 0·250.

2*nd.* They are constructed more readily, easily, economically, and without the aid of special apparatus. Vertical gauges in swift rivers, when even in short lengths along shelving banks, cannot be relied on unless driven home with pile machinery, which becomes an absolute necessity, where the banks are high and scarped.

3*rd.* Owing to the greater number of points of attachment they are stronger, stiffer, and not so liable to accidents from scour. They are also

less open to injury from contact with boats or floating logs, trees, &c., and from boats being tied to them. All these are constant sources of annoyance in connection with vertical gauges, which are often carried away bodily from the causes named.

The site for a gauge having been fixed in reference to the precautions just noted, and the required materials having been delivered, the following procedure should be adopted.

Worked scantlings, $11\frac{1}{2}' \times 5'' \times 3''$.

Rough posts, about 7 feet long and 12 inches diameter.

Iron circular screw-bolts, $\frac{5}{8}$-inch diameter and 11 inches long, exclusive of head with 3 inches length of thread.

1*st.* Excavate holes, (*Fig.* 2,) down the shortest length of inclination four feet in depth, and just sufficient in area to receive the posts provided at central intervals of 10 feet measured along or parallel to the intended slope of gauge, which should be as nearly as possible parallel to that of the bank.

2*nd.* Secure the beds of these holes with well-rammed brickbats or with bricks laid flat, and then jump the posts into them with their thicker ends downwards, and fix them in position by closing up any vacant space round them with *débris*, or earth tightly packed by ramming.

3*rd.* Work the exposed portion of each post laterally, till it has a breadth of nine inches, and then cut through it a 3-inch grove, (*Fig.* 3,) to the depth required for the proper insertion of the gauge-pieces 5 inches × 3 inches in section, which when in position, should be rigidly connected with the posts by iron screw-bolts $\frac{5}{8}$-inch diameter, have their greater dimension of five inches vertical, and be as close as possible to the bank down which they run.

4*th.* The upper surfaces of gauge-pieces should be in the same plane, (*Fig.* 4,) and this very desirable condition should not be sacrificed for minor inequalities in the bank-slope; but when this consists of lengths inclined at widely different angles, (*Fig.* 5,) it may be necessary to break the continuity of the gauge, but even in this case the posts should be 10 feet apart, such distances being always measured along the gauge-pieces.

5*th.* It will generally be possible during the dry season to fix the bottom post, so as to permit of the lowest readings required being taken, but in cases, where this cannot be effected, the lowest gauge-piece can be

supported by the last post, (*Figs.* 6 and 7,) and then projected into the water beyond it. If this method is adopted, the lowest posts should be fixed only five feet apart, and even then it is open to the objection of exposing a weak point to passing boats.

6*th.* After the gauge-pieces have been fixed in position, it will be necessary to cut off the heads, (*Fig.* 8,) of the posts, which would otherwise interfere with the process of graduation described farther on.

7*th.* The jointing of gauge-pieces inclined at the same angle throughout may best be effected by dove-tailed halvings, (*Fig.* 9,) but the joints of pieces inclined at different angles, will require to be more supple, and may consist of a halving, (*Fig.* 10,) or an insertion, (*Fig.* 11,) with a sufficient interval between the ends of adjacent pieces to allow of their revolving round the bolt till adjusted and permanently fixed.

The gauge having been constructed as described, the next process is its graduation into feet and decimals, the greatest care and accuracy being necessary in each of the following operations:—

1*st.* Find the length (l) along the gauge corresponding to each vertical foot of rise. To do this, first measure from the lower end with a levelling staff, the total length (L) (*see Fig.* 12) of the gauge in feet and decimals; next ascertain with levelling instruments, the perpendicular distance (H) between the ends of the gauge in feet and decimals.

Then that $l = \frac{L}{H}$ is clear, for by Euc. Book VI., Prop. II.,

$$AB : BD : AC : CE, \text{ or } H : BD : L : l,$$

$$\text{or, } l = \frac{L \times BD}{H};$$

$$\text{But } BD = 1, \therefore l = \frac{L}{H}.$$

As the utmost accuracy is necessary, the measured length (L) of the gauge may with advantage be compared with this length found mathematically.

The angle, which the gauge makes with the horizon

$$= \sin^{-1} \frac{H}{L} = (\text{say}) \theta,$$

and the length of the gauge $L = H \operatorname{cosec} \theta$.

As everything is based on the height H, this should be very carefully ascertained by taking the mean of several observations.

Example.—If the vertical distance (H) between the ends of a gauge is 11·81 feet, and the length (L) of the gauge is 30·00 feet,

$$L = 11{\cdot}81 \times \operatorname{cosec} 23^\circ\ 11' = 29{\cdot}9975.$$

L as actual measured, is in this case $\frac{1}{1000}$ th of a foot shorter than it should be, an error, however, too small to affect future observations injuriously; 30·00 feet, the measured value of L, may therefore be accepted as correct.

2*nd.* The length of one-gauge-foot having been found, step it off along the gauge from the lower or zero end; next divide each such foot decimally (*Fig.* 13); then mark each graduation by a shallow saw-cut on the face of the gauge, the feet and half-feet graduations being farther indicated by saw-cuts along its *down-stream* side; and finally paint the decimal graduations on the face alternately black and white between the saw-cuts, and the *down-stream* side white with black bands at every half-foot, and black bands and figures at every foot-graduation.

High scarped banks present the most unsuitable sites for inclined, and in fact for all descriptions of, gauges, but this difficulty may be overcome by constructing each gauge along the bank ramped off to a slope of 1 to 1.

It will always be advisable to refer the zeros of gauges to one datum and to establish close to each gauge a permanent bench-mark also referred to it: the best datum is that of the Great Trigonometrical Survey, viz., mean sea level 6·25 feet above the sill of Kidderpur Dock.

A permanent record of the details of each gauge, should always be at hand for ready reference—*vide* Appendices Nos. I and II.

APPENDIX I.—*Example of Gauge in one Slope.—Ramchunder Ghat Gauge.*

Location of gauge.	Description of gauge.	Length in feet and decimals of each gauge foot.	Zero of gauge above mean sea level.	Description of B. M's. established in connections with gauge. M. S. D.	Description of former B. M's from which levels were run to the gauge. M. S. D.	Name and rank of Officers by whom B. M's. were fixed.	Remarks.
On left bank of Choornee river, about 2,000 feet below Hanskhalee Ghat, on road from Buggoolah to Kishnaghur, Nuddeah District.	One slope,..	2·52	11·53	1. Head of 2nd post from upper end of gauge. R. L. 32·11	2. Head of iron spike in root of pipal tree on left bank of Choornee river, about 800 feet below Hanskhalee Ghat on road from Buggoolah to Kishnaghur. R. L. 32·00	1. Mr. A——k, Asst. Engineer. 2. Baboo D——w, Asst. Engineer.	The zero of this gauge was level with water-surface on 13th June, 1876.
	Length in feet from zero, ... 62·78						
	Total height in feet above zero, .. 24·91						
	Highest vertical foot, 24						
	Sál wood posts, .. 7						
	Do. scantlings, .. 6						
	Iron screw bolts, .. 7						

APPENDIX II.—*Example of Gauge in two Slopes.—Baboo Ghat Gauge.*

Location of gauge.	Description of gauge.	Length in feet and decimals of each gauge foot.	Zero of gauge above mean sea level	Description of B. M's. established in connections with gauge. M. S. D.	Description of former B. M's from which levels were run to the gauge. M. S. D.	Name and rank of officers by whom B. M's were fixed.	Remarks.
On right bank of Koomar river, about 3,000 feet below Gambhola (that, on road from Zenana to Cumorcolly, Jeygore District.	Gauge in two slopes, ..		7·81	1. Head of iron rail in roof of man-digested vertical go free, 229 feet-take on high bank from upper end of close to gauge. R. L. .. 38·86	2. Head of gradvertical	1. Mr. L —d. Overseer. 2. Mr. B — f, Asst. Engineer.	The zero of gauge was about 2 feet below water level on 9th June, 1877, when there was no perceptible flow.
	Length of lower slope, ... 20·56						
	Ditto upper slope, ... 40·90						
	Total length, .. 61·46	Lower slope, 28·57 Upper slope, 18·87					
	Height of lower slope, ... 8·67	.. ..					
	Do. upper slope, 21·90	.. ..					
	Total height, .. 30·57						
	Highest vertical foot, ... 30						
	Sal wood posts, .. 7						
	Do. scantlings, 6						
	Iron screw bolts, 7						

NOTE ON INCLINED GAUGES FOR MEASURING WATER IN CANALS.

FIG. 2.

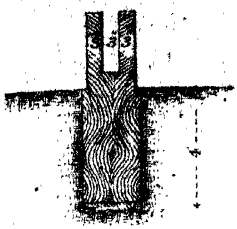


FIG. 3.

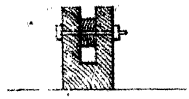


FIG. 4.

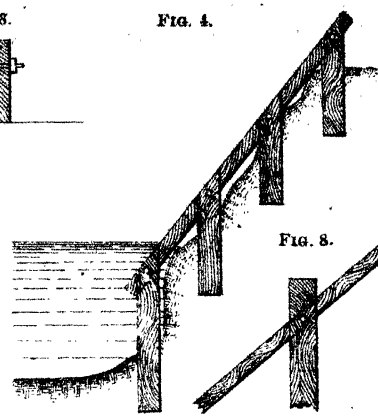


FIG. 5.

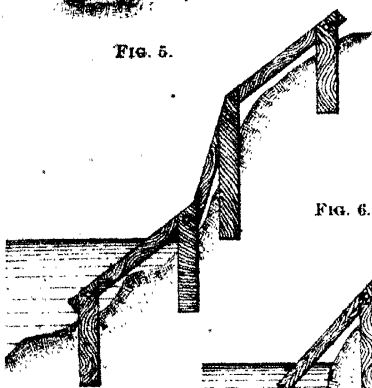


FIG. 8.

FIG. 6.

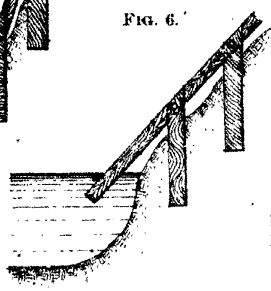


FIG. 7.

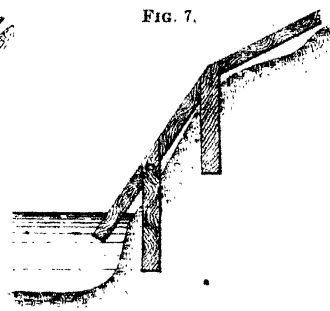


FIG. 9.

Plan

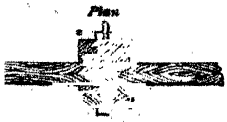


FIG. 10.

Plan

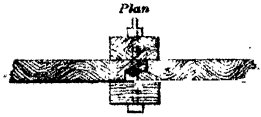


FIG. 11.

Plan

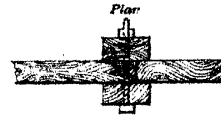


FIG. 1.

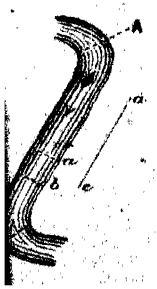


FIG. 13.

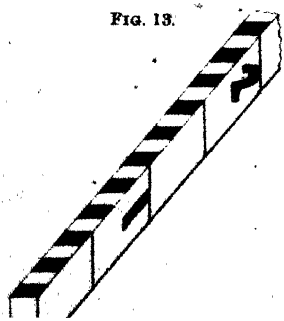
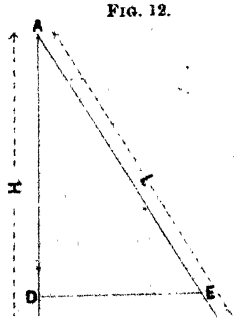


FIG. 12.



No. CCLVII.

BRICKMAKING IN BURMAH.

By O. G. Smart, Esq., *Assist. Engineer.*

The method of making bricks in Burmah is so entirely foreign to the system employed anywhere else, that I think a few remarks on it will not be out of place.

As a rule, in Burmah, when bricks are required, the Engineer has to make his own arrangements even down to mere details before he can get anything done. There are few Contractors in Burmah of any position, and the few that there are, do not care to go in for brick contracts, as it does not pay them so well as other work; and besides, is very risky. Well, to start with. An Engineer has to make bricks for some work he has to construct, and the chances are very great that the work is away from any spot where work has been done before. At first, the only way to get men sharp, is to make the acquaintance of some of the headmen of the village, not the *Government* headmen, corresponding to the Indian Kotwal, but the wealthy men; as the men corresponding to Kotwals, called *Kidangyees*, are always called by the villagers the *fools* of the village, (the only benefit that the Kidangyee really enjoys is exemption from the capitation tax of Rs. 5 per annum.) If there are no wealthy men near at hand, the next thing to be done is to make friends with the villagers. The way this is done is not by making presents, &c., but one must make up ones mind to pass many monotonous steady hours before this can be accomplished. The way to make friends with the villagers is the following—

if you know Burmese well and good, it will be so much the less tiresome for you, if not you must have resource to your interpreter, and failing this, to signs and a great deal of patience. Having had an early dinner, just before it gets dark, you must find your way to the village, and go to the most respectable looking house, or where you see a number of *loobyos*, or bachelors assembled. Forthwith you are offered a seat, cigars are brought out, and you are surrounded by the village folk. At first the conversation is brisk and then it begins to flag. The men go on sucking their cigars (made of tobacco chopped up with chopped sticks and both rolled up in a dry leaf, much resembling the leaf of the pípal tree), and you follow suit: if you can speak, then is the time to commence chaffing any of the fair damsels that are round about, as the Burmans are very fond of chaff, and yet an individual dreads being chaffed. An Engineer who passed out of Roorkee sometime back, went to Arracan, where no labour of any kind had ever been obtained, and having first coaxed the women to work, then chaffed the men into working by comparing the two. Having smoked unlimited cigars for a few evenings with the Burmans, you must then commence trying to get them to work. Whatever you promise, you must be very careful of what you say, because the Burman will expect you to keep your promise to the letter, and cast it up in your teeth if you do not, whilst he has not the slightest compunction in breaking any amount of promises he has made. To get the men to work, you must make friends with them, treat them as equals, as the Burman thinks all men are equal, and in fact make the men fond of you. Having obtained the men to work, you must work *à la Burman*, or all previous trouble will be useless. You must supply the paddy husk, spades, dabs, wheel-barrows, firewood, &c. The Burman will only give the labour *pur et simple*. The process of Burman brickmaking is very simple, and I shall divide it into steps.

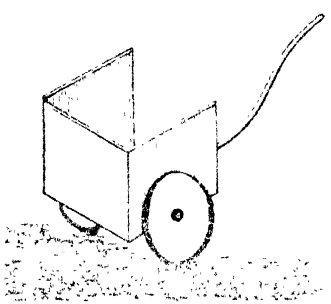
I. As soon as the bricks are to be made, the Burman clears a space of ground, perhaps jungle, perhaps paddy land, on which he can make perhaps 8,000 bricks. He levels this nicely and prepares his own ground. This is the *dastár*, or in Burmese, the *thonga* of the country.

II. Having prepared his ground, the Burman as a rule comes and asks for an *advance* for the first 10,000 bricks, and if you don't give it, he will go away, unless you have plenty of other labour at hand. After this, if the Burman stops, he will commence digging a hole with his

mammoti or *phâora*, (which you must supply, and in fact you must supply every tool or article mentioned.) Having dug or rather turned up enough earth for 1,000 bricks, he pours water over the earth and tempers it by treading. This part of the work the Burman likes as he then can indulge in mud larking, and they pepper each other pretty freely. Having tempered the earth, (and they do this well,) paddy husk is then mixed with the wet earth in the proportion of about three baskets of paddy, (a basket = 1·25 c. ft.) to 1,000 bricks of 12″ × 6″ × 2″, a small quantity being left to sprinkle over the top and for the wheel-barrows. Having thoroughly amalgamated the paddy husk with the earth by dancing about and treading it with their feet, the surface is nicely smoothed off, sprinkled with paddy husk, and allowed to *sweat* in the sun all day. This part of the work is commenced about 4 A.M., and is finished by 7 A.M., when the sun begins to get hot, after which the Burman (who as a rule is a sturdy powerful man), will not work, as he says—he is very delicate.

III. The earth having been allowed to remain in the sun all day, about 5 P.M. the Burmans commence carrying it in small wheel-barrows, (*Fig.* 1,) having solid wooden wheels, to the man who moulds. Before it

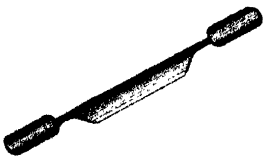
Fig. 1.



is put in the wheel-barrow, the bottom of the barrow is sprinkled with paddy husk, and the earth carried off. The moulder, who has a bowl of water near him, wets the inside of the mould on *the side furthest from him and on the left side.* As a rule the men take up the exact quantity of earth required for each brick, mould the brick and strike it off with *the palm of their hand*, and then go on to the next. A man moulds 1,000 bricks a day with ease. A gang of four men can mould, if they work well, 1,500 bricks a day.

IV. The bricks when half dry are put on end, and when quite dry, their rough sides are *cut with a two-handed dab* or knife, (*Fig.* 2,) and the bricks made tolerably square.

Fig. 2.



V. The bricks are then stacked for counting in lines of 100 each and 10 high, and generally in clumps of 10,000. Up to this point there is a breakage of 10 per cent.

In many places the brick maker considers this as a completion of his work and will not make the kiln or burn it, for which other arrangements have to be made.

VI. When the Burman makes his kiln, he invariably makes it with very small flues, so that there will be no trouble in arching it. The Burman likes to put all his bricks *on end and close together*, so close that one can not put a straw between. When the kiln has been run up 10 bricks high above the flues, it is considered as finished. Occasionally in the middle of the kiln, bricks are left out and a log of wood inserted, and if paddy husk is plentiful, layers of this stuff are laid very frequently. After the kiln is made, a jacket of bricks laid flat is made round it, and the whole plastered over with mud.

VII. The burning is generally also considered a separate item from making the kiln. If a Burman is allowed to do as he likes, he commences burning about 6 P.M., and by 12 midnight of the day following he banks his flues. For the first six hours the burning is slow and then very rapid. The firewood, which must all be collected during the rains previous, is generally sold by the fathom, or a heap of firewood $6' \times 6' \times 6'$. The price varies from Rs. 8-8 a fathom to Rs. 3-8. The Burman considers three to four days cooling quite enough, and begins unloading them. I got very good bricks made by Burmans, but insisted on having larger flues, covering the kiln with a foot of earth after being burnt, and as I was in a hurry for bricks, opening the kiln 10 days after it had been closed. The amount of firewood depends on the quantity that can be afforded. Where I made bricks at the Pegu Lock, firewood was Rs. 8-8 a fathom, and only one fathom for 2,000 bricks could be allowed. The Burman kiln averages 30,000 bricks. Stripping the kiln is also a separate item, and carting is very dear. I had to cart bricks not more than 1,000 feet, and had to pay Rs. 2 per 1,000.

The following is how my rates were made up:—

1st Year.	RS. A. P. Per 10,000.
Moulding, cutting and stacking raw bricks, ...	45 0 0
Making into kilns of 30,000, ...	10 0 0
Burning, ...	3 0 0
Stripping, ...	1 0 0
Firewood, ...	42 8 0
Paddy husk, ...	5 0 0
Tools and plant, ...	5 0 0
	111 8 0
Allowing for breakage, coolies running away with advances, &c., ...	28 8 0
	140 0 0
Carting, ...	20 0 0
	160 0 0

Total cost per 1,000, Rs. 16.

In my second year of brickmaking, I had made better friends with the Burmans, and had also got my firewood cheaper, and had got the men to work differently, and the following were my rates:—

	RS. A. P. Per 10,000.
Moulding, cutting, stacking and making into kilns, ..	65 0 0
Burning, ...	2 0 0
Firewood, ...	35 0 0
Paddy husk, ...	2 8 0
Tools and plant, ...	3 0 0
	107 8 0
Allowing for breakage, (no advances), ...	12 8 0
	120 0 0
Carting and stripping, ...	20 0 0
	140 0 0

Total cost per 1,000, Rs. 14.

The bricks I made were 12″ × 6″ × 6″.

In Rangoon, bricks 10″ × 5″ × 2½″ cost Rs. 11 per 1,000 *at the brickfield.*

The sketches will show the different implements used foreign to India.

O. G. S.

No. CCLVIII.

NOTE ON THE CONSTRUCTION OF THE LARGE MASONRY DAM AT KHARAKWASLA, NEAR POONA.

As a record of practical results on a large scale the following may be of interest to the readers of the "Professional Papers":—

In the construction of the large Masonry Dam at Kharakwasla, near Poona, in 1869-72, considerable anxiety was caused to the Officers in charge of the work by serious discrepancies between the returns of raw material received and of mortar used, which it was considered was larger than could be accounted for by diminution in bulk in progress of incorporation in the grinding mills and by wastage. The following Table gives the results of careful experiments instituted with a view to ascertaining the extent to which the dry materials of mortar diminish in the process of grinding.

The general result is that the amount of diminution is 13·92 per cent., *i. e.*, 100 measures of dry material are reduced to 86·08 in the process of incorporation.

It will be observed also from the Table that the mortar, if left on the ground for a short time before being used, increases in bulk. If removed to the works immediately after grinding a slight diminution in the quantity, due doubtless to wastage in carrying, is the result.

These experiments cleared up the discrepancies above alluded to as it appeared that the difference on the whole work was slightly less even than was accounted for by the diminution in grinding.

The figures are as follows:—

	cubic feet.
Masonry work done up to 31st March, 1877, ...	59,89,313
Dry materials of mortar used, as per Lime Overseer's returns, ...	29,03,136
Percentage of dry materials in work $= \frac{290313600}{5989313} =$	48·47

Now, by the experiments, 100 cubic feet of dry materials became 86·08 in mortar, hence 29,03,136 cubic feet dry materials will give 2499019·26 cubic feet mortar.

Actual percentage of mortar after correction for diminution in grinding $= \frac{249901926}{5989313} =$ .. .. 41·72

The mortar was not measured by the Overseer on the Dam previous to January, 1870, but taking his quantities from that month up to 31st March, 1872, 2¼ years,

We have—

Work done, ...	47,31,547
Mortar used, ...	20,03,730
Percentage of mortar in the work $= \frac{200373000}{4731547} =$	42 34

The masonry used was uncoursed rubble, the stone being trap, and the lime that obtained from the Deccan kankar.

C. J. M.

Date.	Dry materials put into mill.			Quantity of mortar taken out of mill after grinding.	Quantity as measured on being carried from the mill to the works.	Diminution on removal from mill.	Diminution on being carried from the mill to the works as compared with quantity taken out of mill.	Increase on being carried from the mill to the works.	Period of time between removal from mill and carriage on the works.	Remarks.
	Quick lime, furras (each = 2 cubic feet).	Sand, furras.	Total, furras.							
October, 1871,	6·00	10·50	16·50	14 25	14 00	2·25 furras in 16·50 or 13 63 in 100, *i. e.*, 100 becomes 86·37.	0·25 furras in 14·25 or 1·07 in 100, *i. e.*, 1 05 becomes 98·25.		½ an hour.	
20th Decr., 1871,	6·00	10·50	16·50	14·14	13·83	2·36 furras in 15·00 or 14 30 in 100, *i. e.*, 100 becomes 85 70.	0 31 furras in 14 14 or 2·19 in 100, *i. e.*, 100 becomes 97·81.		½ an hour.	It was noticed in making these experiments the bulk of quick lime increased on slaking on an average 31·33 per cent.
7th March, 1872,	6 00	10·50	16·50	14·00	14·35	2·50 furras in 16 50 or 15·15 in 100, *i. e.*, 100 becomes 84 85.		0·35 furras in 14·00 or 250 in 100, *i. e.*, 100 becomes 102·50.	14 hours.	Average, 13·92 in 100.
3rd May, 1872,	6·00	10·50	16·50	14·42	15·07	2·08 furras in 16·50 or 12·61 in 100, *i. e.*, 100 becomes 87 39.		0·65 furras in 04·42 or 451 in 100, *i. e.*, 100 becomes 104·51.	48 hours.	

No. CCLIX.

THE RACK-RAIL SYSTEM APPLIED TO A TRUNK LINE OVER THE ST. GOTTHARD.

BY MAJOR J. L. L. MORANT, R.E., *District Engineer, Neilgherries.*

SOME years ago a Company began to make a line over the St. Gotthard with a capital of seven-half millions pounds. It was to pass over the Alpine Pass of St. Gotthard, from Lake Lucerne on the Swiss, to Lake Como on the Italian side. The following towns were to be connected by the line:—Immenser, Schwyz, Altorf, Biasca, Lugano, Chiasso, and Como. The line was to be 208 miles long, over a very difficult mountainous country. In December, 1876, the Company found that, having expended just four millions pounds, the work was not one-half completed. It was ascertained that the original estimate would be nearly doubled, the excess over it being estimated at 6½ millions pounds. The enterprise then came to a standstill and threatened to collapse. At this juncture, Herr Thommen, Chief Engineer of the railway over the Brenner, published in Vienna a pamphlet, in which he recommended the adoption of the Rack-rail System at a saving of five millions pounds. In doing so, he stated he had no personal nor money interest in the matter, and had long refrained from giving the public his views until he felt sure of his ground. He had often examined the lines of the Rack-rail System and had observed them at work. The results they gave moved him to speak. His advocacy was successful. The Swiss and Italian authorities conjointly, after giving Mons. Riggenbach's new locomotive a severe trial, have just decided to adopt the Rack-rail System in completing the trunk line over the St. Gotthard.*

* This is on the authority of a Swiss ne

Herr Thommen writes in a calm and dispassionate spirit. His official position and the success of his support gives his observations great weight. They merit the attention of Indian Engineers.

The abortive St. Gotthard line was to have had gradients of 1 in 40 and 1 in 37, and to have been worked by locomotives trusting entirely, in the ordinary way, to adhesion. When its monetary crash came, Herr Wettli, Locomotive Superintendent of the Zürich Canton, proposed to lessen the cost of completion by introducing grades of 1 in 25 and 1 in 22½, worked by adhesion locomotives. Such gradients exist elsewhere: how do they answer? In France, between Enghien and Montmorency, there is a short incline 1200 yards long of 1 in 22½; it is approached by long stretches of easy gradients: its inconveniences are not insupportable. The Wetliberg line in Switzerland has actually a gradient of 1 in 14⅔, worked by adhesion locomotives. It is a very short line, constructed by Mons. Tobler of Zürich. Up it a locomotive and tender weighing 24 tons draw double their own weight: no complaints against it are heard. These are short lines which can hardly help us in the discussion of a line 208 miles long.

We will turn to others which will better serve our purpose. In Piedmont in Italy, the Giovi Incline crosses the Apennines between Alessandria and Genoa; its grades are 1 in 28⅔. In the Caucasus, the line between Poti and Tiflis, has gradients of one in 22½. Each locomotive of Mons. Gottschalk draws on trial trips, over the Steigungen between Pontedecimo and Busella for a length of 6¾ miles, 130 tons up inclines varying from 1 in 35½ to 1 in 28½. The steepness of all these grades has been found very inconvenient, and has given rise to bitter complaints. At length the authorities in all three cases—the Italians, the Russians and the Swiss, quite independently of each other—resolved to reconstruct these lines at a large outlay, and to bring their grades down to a maximum of 1 in 40. Projects to effect this are in preparation.

Nor is the evil confined to these steeper grades. The engines of the Semmering and Brenner Passes in Austria, weighing 52 and 50 tons when designed, were each calculated to draw trains on 64 axles of 230 and 200 tons weight, respectively. All the working and other expenses were estimated on this assumption. But practice proved that a single locomotive could not systematically drag trains on 64 axles weighing more than 181 and 147½ tons. This was solely due to the long gradients of

1 in 44½ and 1 in 40 which extend for 22½ and 31¾ miles, for some distance the gradient being only 1 in 66½. Herr Thommen (and the greatest possible reliance can obviously be placed on his statement from the official position he holds) states, that the locomotive service alone on the Brenner Pass, with a continuous gradient of 1 in 40 for a length of 32 miles, has been found to be 50 per cent. more than on more level lines; and that on gradients of 1 in 25 these expenses are doubled. Thus long steep inclines worked by adhesion locomotives, are everywhere wholly unproductive, their working expenses exceeding their receipts, the deficits being made up by the profits gained by the more level lines belonging to the same Companies which hold the mountain lines.

From these specific cases Herr Thommen enters upon a few general practical considerations. It has been asserted that safety can be insured on steep gradients by reduced speed; but in practice this cannot be relied upon. The engine drivers are often induced to increase speed beyond safe limits, to make up for lost time or for some other reason. Again: in the case of two locomotives to one train. Supposing a double train, weighing 300 tons, to be drawn by two locomotives each weighing 50 tons on any steep gradient, one locomotive will be in front and the other in rear of the train. Theoretically the front engine will be always pulling exactly its half load of 150 tons, and the rear locomotive pushing exactly its half load of the same weight. But in practice it is impossible always to insure the two locomotives thus working together. For example:—When on an up gradient the front locomotive enters a tunnel, it immediately loses one-sixth of its ordinary adhesion, and the wheels begin to slide, thus throwing a very much greater weight than ordinary on the rear or pushing locomotive: this extra weight crushes the whole train, and is apt to lift up off the rails the lighter trucks composing it. Or, if they reverse be the case, and the wheels of the pushing locomotive lose adhesion, that locomotive falls back and a very much greater weight than ordinary is suddenly thrown on the couplings.

Herr Thommen now turns to the consideration of the Rack-rail System of traversing steep inclines, and makes some very important observations. This system has the advantage over others, like Agudio's, Wettli's, &c., of considerable experience. It has been put to a practical test, and is now satisfactorily at work, in many parts of the continent. It has passed out of the region of theory into that of practical use. Very steep mountain

lines on this principles have been economically constructed, and worked with as much safety as lines over a flat country. In all the eight places where it has been adopted, it has proved itself as solid, secure, regular in working and as easy to manage as adhesion lines over flat countries, and to require less to be expended on its repairs. It does not require special carriages or wagons, and no accident has as yet occurred on any of its lines. It combines security with economy. The Rack-rail System was at first somewhat limited in its application; it has since been gradually improved and extended, and now promises to be universally applicable. No one can witness, without admiration, the steady regularity with which the toothed-wheel locomotives ascend inclines, nor without greater admiration how quietly and safely they descend them. How differently adhesion locomotives behave. They are seen moving up steep inclines with difficulty, here the wheels slipping on account of the greasiness of the rails, there brought nearly to a standstill and then creeping on again: they waver and their progress is irregular. In descending, the locomotives are seen running down with an uncomfortable speed, all the brakes smoking-hot and still scarcely manageable. A toothed-wheel locomotive can be stopped in its descent at a moment's notice, and neither wind, rain nor snow have any appreciable effect on the working of its line; while, *au contraire*, these conditions of the weather greatly affect the adhesion of ordinary locomotives, which can never in descending be speedily controlled. And lastly, Herr Thommen actually asserts, that, the Rack-rail System, in spite of the additional cost of its central rack-rail, is mile for mile cheaper than the ordinary smooth line system when applied to mountains.

Hence Herr Thommen strongly advocates the application of the Rack-rail System to the St. Gotthard line. It alone will drag the Company out of its formidable difficulties. The contemplated excess will be reduced by more than 5 millions pounds from $6\frac{1}{2}$ to $1\frac{1}{4}$ millions pounds and, whereas by the adhesion system, the dead weight dragged forwards and backwards over the 208 miles of the mountain line will be nearly 50 millions of tons, by the Rack-rail System it will be only a little over 25 millions of tons. He therefore earnestly recommends the application of the Rack-rail System on a long trunk line of mountain railroad, not at all as a makeshift, but as absolutely the best system yet invented.

y, 1877.

Since writing the above, we have received from Mons. Riggenbach a printed extract in German, from the Travelling Journal of a Swiss Engineer, a translation of portions of which will be of interest.

(Translations from the Journal).

On the 29th of September, we began our journey over the St. Gotthard to Lugano, from which we visited Luino. From Lugano we travelled through Mailand to Genoa, from which we returned home over the Simplon.

As funds are not available for a permanent line through Mount Cenere, I beg to suggest the following temporary line between Bellinzona and Lugano. The trunk road between these two towns is an excellent one, quite broad enough for a line on the metre gauge. In two or three places on its southern side the road would have to be altered, as the curves are too sharp; and some expenditure would be needed to reach the Railway Station of Lugano. The cost of all this I estimate at £4,000.

The length of the trunk road is about 13 miles, and the cost per mile of laying rails and providing rolling stock would be about £3,500. Thus, the whole cost would be about £50,000. The 13 miles is now traversed in 4½ hours: the locomotive would do it in 1½ hours. This *ad interim* line could be worked by small locomotives, such as were constructed at Aaran for Herr C. Honegger of Rüti, and like those on the Wasseralfingen line, where they have worked very satisfactorily. These cog-wheel locomotives would each weigh only 6 tons, and draw on a gradient of 1 in 20 a train of 30 tons or 120 passengers. The working expenses of the railway per train mile would be 1*s.* 3½*d.* Similar cog-wheel locomotives, weighing 11 tons, have drawn up gradients of 1 in 20, trains weighing from 50 to 60 tons. Cog-wheel locomotives on the mixed system, to run over ordinary lines as well as those with the rack-rail, travel at the rate of 15½ to 18½ miles per hour over the smooth rails, and at from 6¼ to 7½ miles an hour over the rack-rail. On the lines on which they have been used, the gradients have been as steep as 1 in 10, and the radius of the curves as sharp as 65½ feet.

After a short stay in Genoa we returned home over the Apennines. The railway here has gradients of 1 in 30, with a tunnel 2 miles long, through which the gradient is 1 in 33. The line is admirably constructed,

but its working expenses are very heavy. The gigantic locomotives, weigh with their tenders 70 tons. Heavy goods trains are drawn by three such locomotives, two in front and one behind. Locomotives thus weighing no less than 210 tons have to transport goods up a height of over 1,000 feet in 1½ hours. The Directors of this line have been apprised of the advantages offered by the Rack-rail system, which could at no great cost be applied to their line. They do not see their way to this at present, although the Rack-rail system would reduce their working expenses by 35 or 40 per cent.

A Rack-rail line with gradients of 1 in 20 has been traced from Friburg through the Höllenthal to Neustadt. Its Surveys and Estimates have been completed, and will be laid before the Baden Parliament during the winter. It will in all probability receive early sanction, as the Minister of Public Works is strongly in its favour, being convinced that the Rack-rail system is the only one which can be constructed over mountains at a moderate cost with a good prospect of paying a dividend. The line between Offenburg and Dowaneschingen, which crosses the same mountains, has been constructed on the usual adhesion plan. It has cost so large a sum of money that the Baden Government has resolved to undertake through their mountains no other lines on the same system. Moreover, its working expenses are so heavy, that in spite of an enormous traffic, its receipts barely cover them. The mountain portion of this line consists of tunnels and curves which cause the rails and rolling stock to wear out with extreme rapidity.

J. L. L. M.

14*th Decr.*, 1877.

No. CCLX.

STATISTICS OF NARROW GAUGE RAILWAYS IN NORWAY.

Communicated, with Remarks, by MAJOR T. F. DOWDEN, R.E., A.I.C.E.

THE Author, in presenting the Statistics of the Norwegian Railways, kindly furnished him by the Director, Mr. Carl Pihl, in the exact state in which they were received, has abstained from general comment on the figures, which would make the paper unnecessarily long. The importance to be attached to them in support of any particular view will often vary with the views of the enquirer, and the Statistician may be content with providing figures in the most generally intelligible and acceptable shape derived simply from facts.

Theory and Practice, aided by access to well arranged statistical records of working will, when brought to bear in one focus, no doubt soon lead to useful conclusions being arrived at by the body of persons interested.

It remains only to give Mr. Carl Pihl's sketch of the situation in Norway, which may be done as nearly as possible in his own words. A short Memorandum of the principles and points to be kept in view in considering the figures of Railway statistics is appended.

Extracts from Letter of 14th June, 1877.

"You will find the Tables comprise results of the two 4 ft. 8½ in. gauge lines at present in operation in Norway, and also those of the Swedish State Railways, working pretty much under the same circumstances as our own. I have put the results derived from the four narrow gauge lines (3 ft. 6 in.) side by side, so that comparisons may be made between the different items of expenses in working on both the systems.

"Norway * * * * is in its character a mountainous country with a total area of 122,000 square miles, of which only 3 per cent. is cultivated and arable land, 21 per cent. forests, 76 per cent. mountains, lakes and wastes (of which half is above the line of growth of forests). The number of inhabitants is only 1,800,000, of which about 35 per cent. is employed in agriculture and forestry, 5½ per cent. in navigation and fishery. Our country has a large but thinly populated area with little power of production; and it can therefore, be no promising

field for development of railways. Only one or two of our railways have much traffic, the others have a comparatively small traffic, and give little or no surplus.

"My opinion, based upon the experience of working the railways of the 3 ft. 6 in. gauge compared to the others is, that for a small traffic the economy is decidedly in favour of the less costly system, where the whole apparatus throughout is proportioned with a view to meet the comparatively limited requirements, and our experience on the most busy line on the 3 ft. 6 in. gauge, (Christiania-Drammen,) has given rise to no suspicion, that the same good results do not hold good, even after a considerable development of traffic. You will, by studying the statistics, perceive, that the different items of expenses, where comparison should be drawn, such for instance the maintenance of line, expense for rolling stock and traction, all shows certainly quite as good, and even better, results than on the ordinary gauge. One point, which in my opinion, shows favourably is, the better proportion between the dead weight and carrying capacity of the carriages and wagons, and also the *absolute* smaller weight of the narrow gauge stock. With regard to the first, we all know its importance, but what seems not to have been so well understood by many, is the comparative ease with which this can be attained for any wagon, provided it is made to carry a *heavy* or *large* weight, as of course the wagon with but an insignificant addition in weight (from stronger springs and perhaps axles) may be made to carry even twice as much weight in one case as in the other. With regard to the second, or the absolute smaller weight of the rolling stock, I consider this, especially when coupled with a limited traffic, to be of equal and even greater importance, when considering that as a rule the wagons are but seldom loaded to more than 25 to 70 per cent. Tables G., H. and I., are intended to show how this influences the working.

"With regard to your special question, as to the relative cost of passenger and goods trains at high and low velocity, I can give you no definite or satisfactory answer. Not only the general profit (Gradients and Curves) of our lines, but also economic reasons forbid high speeds. We run, however, our trains with the same speed on both the gauges, but have none of what you would call fast trains. We have no exclusively passenger trains but all of them are mixed, or doing more or less service for the goods traffic, but no shifting of goods wagons is allowed in the trains specially run for passengers. The speed they are run at varies between 20 and 25 miles an hour between stations—special goods trains of course being excepted."

Principles and points to be kept in view in considering Railway Statistics.

The dividend of Railways is made up as follows:—

$$\text{(I.)}\quad \frac{\text{Receipts} - \text{Working Expenses}}{\text{Capital.}}$$

This may be further represented by the following—

$$\text{(II.)}\quad \frac{(\text{Quantity of Traffic} \times \text{Rates}) - (\text{Quantity of Traffic} \times \text{Working Expense per unit})}{\text{Quantity of Traffic} \times \text{Capital per unit.}}$$

and the amount will vary therefore as—

$$\text{(III.)}\quad \frac{\text{Average Rate} - \text{Expenses per unit}}{\text{Capital per unit.}}$$

The dividend as regards this fraction will be greatest when the Denominator is least, or when the Capital employed per unit is least (1), when the rates are highest (2), and when the expenses are least (3) per unit.

For a given style of construction the Capital will be least when the amount sunk on the whole works is in proportion to the number of units of traffic to be accommodated, or conversely, when the line is fully employed.

The Rates will be highest according to the demand for transport and the willingness and ability of the customers to pay. The rates need only be reduced in order to attract the full traffic for which the capital provides; beyond that point they may be increased with increased demand, unless we are prepared to increase the Capital account.

To increase rates, however, is to give a check to advancement; it could also not be carried out in the face of a healthy competition.

To increase the capital account without increasing the carrying powers in a greater ratio will not tend to increased dividend from quantity of traffic.

The expenses will be least per unit, when the line complete in every respect in all its component parts, has the full traffic for which the capital provides. They will decrease per unit as that quantity is gradually attained, and will increase when that limit is passed.

As the Dividend will have the first consideration with the investor, he will look about for a possible means of increasing it, when his original capital is being fully worked.

By doubling a line we know that we double the capacity without doubling the expense of construction, and this in itself must lead to increased dividend, unless the working expenses are increased; this is not the case but the reverse; in fact, by increasing the number of lines of rails they are diminished, per unit through the so-called fixed charges.

But before this process is gone through, the Capacity of the single line may be marvellously increased, in a greater ratio than the Capital Account if the original works did not contemplate a maximum but a minimum traffic. This may be done by adding to some of the parts of the Railway, noteably, the weight of Rail, the quantity and weight of Rolling Stock, the Brake power, and the number of block clear lengths of Line.

Such an arrangement has also this recommendation, that it tends to increase the total working expenses in a less ratio than the increase of Capacity; and, consequently, to decrease the expense per unit and increase the dividend from this cause, and also by an increased quantity of traffic per unit of capital. The charges for trains and signalling are increased, the former by additions to Rolling Stock and Brake repairs, the latter by signal and point arrangements at shorter intervals. A slight addition is made to Maintenance expense, and to the General and

so-called fixed establishments, apart from the train working; these forming about half the working expenses, are added to very slightly in proportion to the number of trains which may be run.

No doubling of lines is therefore ordinarily likely to take place till single ones have been fully developed. The process of increasing the power of the single line, tends to increase the Dividends, without a necessity for increasing the rates; but, it has the advantage also of admitting of some reduction of rates, while still leaving some increase of dividend.

To such a promising state of things, the first consideration is to seek a limit; this limit is evidently first, that due to safety in working, for it cannot be conceded that dividends are to be increased at more than the ordinary risk of life. Moreover, this limit fixes the point when the expenses begin to rise. A single smash may cost a large sum, not only not spent unremuneratively, but tending actually to reduce the carrying power and the earnings during the process of repair.

The over work of a line, for the style of construction and appliances available, from whatever cause, produces an excess working expense and loss of power in a similar manner, by premature wearing out of the Rails, Tyres, &c., which it would have been cheaper to have made more durable by a slight addition to the capital cost; the limit to the wear, prescribed by the repairs not costing more than the interest on the capital, is evidently to be kept in view.

Again, by increasing the number of crossing places and shortening the Block clear lengths of a single line, the through speed is ultimately considerably reduced, and a limit is imposed in this direction, largely affecting the capacity of the line in ton-mileage per hour, and increasing the cost per unit.

The Board of Trade Returns, however, give ample evidence of a large development on English Railways.

		Miles single line	Cost £	Cost per mile single line of rails £	Train miles	Train miles per mile	Weight of trains	Trains per day
Actuals,	1854	14,156	286,068,794	20,400	82,978,763	5,880	150 tons.	16·0
	1875	25,556	630,223,494	24,600	209,528,186	8,190	240 „	22·5
Ratios,	1854	100	...	100	...	100	100 „	100
	1875	181	...	121	...	139	160 „	148

The only figure assumed is the weight of trains,* which has increased (probably regularly) to about four times what it was in 1840, namely, 63 tons on the average.

* The total vaporisation of engines per hour has increased four-fold since Pambour conducted his experiments in 1840.

The ratio of increased capacity is represented by the train mileage per mile × by weight of trains, or $\frac{100}{139} \times \frac{100}{160}$ or $\frac{100}{222}$; thus, while the cost of the single line has only increased 21 per cent., the capacity has increased by 122 per cent.

Also the working expenses and receipts per train mile have remained almost constant, while the weight of trains has increased 60 per cent., showing a reduction to about that extent in the working expenses and rates per unit. While a greater speed has been maintained and a larger number of trains run; in other words, a better service has been afforded.

What has been stated will show how profitable Railway enterprise must be, especially with an established monopoly; how possible it is to introduce it in a comparatively cheap manner and develop it as trade and traffic increase; how trade and traffic may be themselves increased by timely liberality in reductions of rates; while judicious management may at the same time secure some increase of dividend for the Railway.

It will thus now be observed, that it is difficult to compare the working of Railways unless the above principal considerations are all borne in mind.

Also in order to convey a comprehensive idea of the effect of the Railways compared; it is desirable that statistical figures relating to cost, traffic, and working expenses per mile, &c., and the gradients, speed, &c., should all appear in as close juxta-position as possible, so that dissimilarity of conditions may at once be recognised, and the value of the differences estimated if possible.

The net result of the whole working summed up in the 'Dividend,' is however, what chiefly interests the investor, and as long as the dividend is a good one, few questions are likely to be asked.

But the State, or the Country generally, cannot be said to be so much interested in seeing railway dividends high, as in possessing an ample and cheap system of communication; its Railway Officers are charged with the important duty of ascertaining how this can best be done.

The English Railway system affords very little statistical information regarding the working. Questions affecting constructive details have mostly excluded the question of gauge, owing to the necessity for uniformity in that respect.

An experiment is being tried in many countries, for introducing a cheaper class of Railway to suit a small traffic by a contraction of the

gauge, and any evidence that may be forthcoming on the relative economical value of the measure, cannot but be highly interesting and valuable.

But it has been attempted to be shown, in the foregoing slight sketch, of the influences that affect the construction and working of all Railways, whatever the gauge may be, what a very careful analysis of the causes which affect the figures appearing in a statistical enquiry is necessary, and consequently how difficult it must be in practise to establish, by that method alone a claim to superiority in regard to cost and performance, (which must be considered together), for any particular gauge or style of construction, unless the entire similarity of the conditions in other respects prevents a difference being assigned to any other cause.

It has been shown that the net useful result, is influenced by the Receipts, Expenses, the Capital, its Mode of Expenditure, and the Quantity of Traffic. It will be further influenced by the location of the Railway.

For the local Receipts will be in proportion to the density of population, and the power and the willingness of the people to pay, and the through receipts per mile will be in proportion to the length of the Railway and importance of the trade and traffic accommodated.

The Capital Outlay will be in proportion to the flatness or hilly nature of the country. The longer the line, the greater the number and size of the obstacles, in the way of rivers and hills, it is likely to have to traverse, and on this account trunk lines are usually more expensive per mile to construct than secondary, and secondary than short branch lines: Railways constructed in the hills are more expensive than in the plains per mile, and so on.

The Expenses, per unit, will be less on level lines than on undulating ones, and on long than short, also less in rural districts, where wages are low than in highly developed districts, producing the more valuable articles of trade, and in the neighbourhood of towns.

Now these facts clearly show that it is possible to adapt Railway Construction to suit the requirements of the financial situation and the probable traffic, within a very wide margin, to produce a given dividend without reference to the question of gauge.

In dealing with the Statistics of Railways, therefore, it is better to afford the fullest information on all the points referred, to in the above reduced to its simplest form.

At starting, the consideration of a standard unit of useful work done

has to be determined on. The absolute measure of the total work done, could only be made by reducing everything to the mechanical equivalent of weight raised through space, as the ton raised one foot high; this could no doubt be done as regards all the operations connected with the weights moved.

But a more convenient and practical measure of the *useful work* on Railways is that of weight moved over distance, as the ton over a mile.

This measure has an advantage over the train mile unit, which applies only in some cases, and is liable to be used when not suitable, as in the division of expense between passengers and goods on the same railway.

With a careful record of the gross ton mileage, the useful work done, measured in gross load moved over space in a unit of time can be ascertained. Only by some such method can account be taken of the power expended and the cost of it, under the different conditions of working trains on the same, or different lines of rails.

The cost of the useful or paying work, will thus evidently not depend only on the distance run or weight moved, irrespective of time, but on the whole power expended and the cost of it in a unit of time.

The paying work or freight moved a mile will seldom form a fixed proportion of the total or gross weight moved a mile. No more importance is to be attached to the absolute, or average proportion of freight to gross loads than to all the other considerations effecting the working; the former must be tested by the expense per unit, and the latter by the empty haulage and traffic exigencies for augmenting the total receipts wherever they may offer.

The speed is as much an element of economical working as the load, and the maximum effect is only to be got by a consideration of both. An increase of one generally leads to a decrease in the other on the same Railway; there is a point when the greatest *ton-mileage* is being performed.*

The gross ton mile sufficiently nearly represents the unit of mechanical power expended in doing useful work irrespective of the mode of working, to which fixed constants can be applied for the effects of gravity on different lines, and for the different speeds employed on the same line, in order to represent the cost, these constants could be calculated with Mathematical exactness once for all for every Railway or district of it.

* It appears that the superior average speed available on the 4′ 8½″ gauge in Norway is not employed.

TABLE A.

Data for Construction.

Details	Chrania-Eidsvold	Lillestrom-Kongsvinger	Hamar-Aamot	Throndhjem-Storen	Drammen-Randsfjord	Christiania-Drammen
Gauge of line, ...	4′ 8½″	4′ 8½″	3′ 6″	3′ 6″	3′ 6″	3′ 6″
Number of miles opened, ..	42·0	71·0	39·9	30·1	89·6	4·7
Weight of rails in lbs., per yard, ...	60 &72	62	37	37 &41	40	40
Ruling or steepest gradient "up" line, ...	$\frac{1}{40}$	$\frac{1}{200}$	$\frac{1}{80}$	$\frac{1}{42}$	$\frac{1}{60}$	$\frac{1}{80}$
Corresponding resistance in lbs., per ton, ...	66 0	21·2	36·0	63·3	47·3	38·0
Tractive power per each ton weight of driving wheel pressure, ...	5·6	17·0	10·4	5·9	7·9	9·8
Proportion, ...	0·95	2·98	1·76	1·00	1·34	1·66
Ruling or steepest gradient "down" line, ...	$\frac{1}{60}$	$\frac{1}{250}$	$\frac{1}{75}$	$\frac{1}{53}$	$\frac{1}{75}$	$\frac{1}{70}$
Corresponding resistance in lbs., per ton, ...	47·3	19·0	42·0	50·7	39·9	42·0
Tractive power per each ton weight of driving wheel pressure, ...	7·9	19·7	8·9	7·4	9·4	8·9
Proportion, ...	1·07	2·66	1·20	1·00	1·24	1·20
Difference in level between terminal stations, ...	396	87	3·12	161	444	0
Height of summit or ascent from the lowest terminus,	687	156	459	408	634	435
Cost of construction per mile of line, ... £	11,269	6,072	2,595	5,330	4,357	7,568
Opened for traffic, ..	$\frac{1}{0}$ '54	$\frac{3}{4}$ '62, and $1\frac{4}{1}$ '65	$\frac{6}{10}$ '62, and $\frac{9}{10}$ '71	$\frac{6}{8}$ '64	$1\frac{5}{11}$ '66, and $\frac{1}{1}\frac{3}{0}$ '65	$\frac{7}{10}$ '72

TABLE B.

Traffic Results.

Extract of the Traffic Returns for 1875.

Details	Gauge, 4′ 8½″		Gauge, 3′ 6″			
	Christiania-Kidsvold	Lillestrøm-Grandsen	Christiania-Drammen	Drammen-Randsfjord, Branches to Konysberg and Krodrem	Hamer-Aamot	Throndhjem-Storen
of miles opened for traffic, ..	42·0	75·6	32·9	89·6	41·3	30·1
onstruction, per mile of line, .. £	11749	6453	7177	4295	2809	5437
of train miles, ...	138,641·3	199,602·9	168,793·1	191,324·7	62,691·3	45,570
„ „ *per mile of line*, ...	3301	2640	5130·5	2135·3	1518	1514
„ passengers carried, ...	330,228	165,696	608,646	325,789	115,424	130,047
„ „ miles, *per mile of line*,	136,506	57,217	243,472	59,981	39,282	57,998
„ goods ton miles, *per mile of line*,	149,154	105,259	45,629	38,043	14,604	22,593
„ „ „ „ „ *train mile*, ..	45·2	39·9	8·9	17 8	9·6	14·9
of passenger and goods ton miles rain mile, ...	53·0	45·3	13·3	21·1	12·1	17·8
ad, including engines, wagons, and ages, *train mile*, ...	213·6	168·8	80 0	83·5	62·8	84·6
Receipts.						
er receipts, per mile of line, .. £	457 8	171·8	723·1	167·7	110·3	151·5
„ „ *train mile*, .. *s.*	2·8	1·3	2 8	1·57	1·45	2·00
eccipts per mile of line, ... £	1164·9	373·5	375·1	210·7	143·3	198·0
„ „ *train mile*, ... *s*	6 9	2·8	1·5	1·97	1·89	2·62
AL RECEIPTS per mile of line, .. £	1708·7	555·5	1127·4	400·8	260 6	359·0
„ „ *train mile*, .. *s.*	10·4	4·2	4·4	3·75	3·43	4·74
Expenses.						
nent and offices, per mile of line, £	49·0	16 9	45·3	21·9	17·9	22·1
„ „ „ *train mile*, .. *s.*	0·30	0·13	0·18	0·20	0·24	0·29
xpenses, per mile of line, ... £	233·1	85·8	220·7	77·2	69·6	60·1
„ „ *train mile*, ... *s.*	1·40	0·65	0·77	0·72	0·92	0·79
lve Department, per mile of line, £	272·2	109·8	232·1	81·0	53·7	76·6
„ „ *train mile*, .. *s.*	1·60	0·83	0·90	0·76	0·71	1·01
partment, per mile of line, ... £	50·4	44·0	73·4	28·4	9·1	22·1
„ „ *train mile*, .. *s.*	0·31	0·34	0·29	0·27	0·12	0·29
e of line, fences and bridges, *per line*, ... £	256·7	117·9	130·5	83·2	58·4	111·
„ „ per ile, ... *s.*	1·60	0·89	0·51	0·78	0·77	1·4·
e of buildings, station yards, tele- per mile of line, ... £	117·7	47·7	51·7	20·0	12·9	13·

TABLE B.—(*Continued*).

Traffic Results.

Extract of the Traffic Returns for 1875.—(Continued).

Details	Gauge, 4′ 8½″		Gauge, 3′ 6″			
	Christiania-Eidsvold	Lillestrøm-Grandsen	Christiania-Drammen	Drammen-Randsfjord, Branches to Konsberg and Krydsrem	Hamar-amot	Thereafter
Maintenance of buildings, station yards, telegraph, *per train mile*, ... *s.*	0·72	0·36	0·20	0·19	0·17	0·
Other expenses, *per mile of line*, ... £	110·1	51·1	93·3	41·4	10·7	7
„ „ „ *train mile*, .. *s.*	0·65	0·38	0·36	0·39	0·14	0·
Total expenses, *per mile of line*, .. £	1089·3	473·2	847·0	353·1	232·2	31
„ „ „ *train mile*, .. *s.*	6·60	3·58	3·30	3·31	3·06	4·
Surplus, per *mile of line*, ... £	619·4	82·3	280·4	47·7	28·4	4(
„ „ *train mile*, ... *s.*	3·8	0·62	1·10	0·44	0·37	0·
„ in per cent. of invested capital, .. %	5·577	1·357	3·683	1·109	0·947	0·(
Average Passenger fares, *per mile*, farthings,	3·22	2·88	2·85	2·68	2·69	2·
„ Goods rates, *per ton mile*, „	7·51	3·56	7·89	5·31	9·40	8
„ Receipts, per *gross, ton mile*, „	2·31	1·19	2·64	2·15	2·62	2·
„ Expenses, „ „ „ „	1·49	1·02	1·98	1·90	2·34	2

* Deduced from the figures above.—T. F. D.

Traffic Results.

TABLE C.

Average for the Quinquinium 1871-75.

		4′ 8½″ Gauge			3′ 6″ Gauge		
		Chania-Eidsvold	Lillestrøm-Kongsvinger	Swedish Stubebawå	Hamar-Aamot	Throndhjem-Støren	Drammen-Randsfjord
Number of miles opened for traffic, ...		42·0	75·6	805·0	39·9	30·1	80·5
„ „ locomotive miles, per mile of line,		5172	2624	3396	1456	1960	2565
„ „ train miles „ „ „ „ ..		3215	2570	3256	1312	1502	2183
„ „ carriages and wagons miles, per mile of line, ...		64,953	40,469	50,322	10,564	14,336	20,977
„ „ carriages and wagons, per train mile,		20·2	15·7	15·5	7·9	9·5	9·5
Net load of goods per mile of line, ton miles,		145,061	84,447	100,758	11,846	17,894	39,650
Proportion, ..		12·25	7·13	8·50	1·00	1·51	2·93
Net load of goods and passenger per mile of line, ton miles, ...		153,612	88,222	110,812	14,191	21,926	39,130
Proportion, ..		10·82	6·22	7·81	1·00	1·54	2·76
Gross load, including engines and wagons, ton miles, per mile of line, ...		640,435	356,425	512,551	70,334	110,130	162,673
Proportion, ..		9·11	5·07	7·29	1·00	1·59	2 31
Gross load, including engines and wagons, ton miles, per train mile, ...		199	139	157	54	73	75
Proportion, ..		3·70	2·57	2·91	1·00	1·35	1·39
Net load in per cent. of gross load, ..	%	23·99	24·25	21·60	20·20	19·9	24·1
Proportion, ..		1·58	1·63	1·42	1·33	1·31	1·59
Effect of one pound of coal in ton miles, ..		0·48	0·81	..	0 40	0·34	0·47
Proportion, ..		1·41	2 38	..	1·18	1·00	1·38
Receipts.							
Passengers' receipts, per mile of line, ..	£	369	141	329	93	125	138
Proportion, ..		3·99	1·51	3·55	1·00	1·35	1·49
Goods' receipts, per mile of line, ..	£	1061	302	450	121	156	178
Proportion, ..		8·74	2·49	3·71	1 00	1·29	1·47
Total receipts, per mile of line,	£	1539	454	788	223	281	333
Proportion, ..		6·91	2·04	3·54	1·00	1·29	1·49

TABLE C.—(*Continued*).

TRAFFIC RESULTS.—(*Continued*).

		4′ 8½″ GAUGE			3′ 6″ GAUGE			
		Chania-Eidsvold	Lillestrom Kongsvinger	Swedish Stalebawå	Hamar-Aamot	Throndhjem-Storen	Drammen-Randsfjord	Christiania-Drammen for 3·26 years
Expenses—(Continued).								
Management and offices, per mile of line, ..	£	47	15	12	15	19	20	40
Proportion, ..	„	3·91	1·21	1·00	1·29	1·55	1·64	3·34
Station expenses, per mile of line, ...	£	186	67	110	52	50	59	185
Proportion, ..		3·69	1·34	2·19	1·04	1·00	1·17	3·63
Locomotive Department, per mile of line, ..	£	225	108	135	42	65	61	188
Proportion, ..		5·38	2·58	3·24	1·00	1·56	1·46	4·50
„ „ per mile of line, ..	£	1·40	0·83	0·70	0·64	0·87	0·56	0·76
Proportion, ..		2·51	1·50	1·47	1·14	1·55	1·00	1·35
Wagon Department, per mile of line, ..	£	58	42	35	10	15	20	50
Proportion, ..		5·62	4·10	3·45	1·00	1·44	2·00	4·89
„ „ per wagon mile, ..	*s.*	0·017	0·021	0·011	0·020	0·021	0·020	0·022
Proportion, ..		1·30	1·53	1·00	1·41	1·53	1·41	1·65
Maintenance of line and bridges, per mile of line, ...	£	2·14	100	120	43	89	71	106
Proportion, ..		4·96	2·31	2·78	1·00	2·06	1·65	2·45
TOTAL EXPENSES, per mile of line,	£	886	387	440	189	256	261	673
Proportion, ..		4·68	2·04	2·33	1·00	1·35	1·38	3·56
„ „ per train mile,	*s.*	5·51	3·01	2·68	2·99	3·40	2·47	2·70
Proportion, ..		2·24	1·22	1·08	1·17	1·38	1·00	1·10
„ „ per gross ton mile, ...	*s.*	0·027	0·021	0·017	0·055	0·046	0·032	0·037
Proportion, ..		1·7	1·4	1·0	3·4	2·9	2·0	2·3
EXPENSES in per cent. of receipts, ..	%	57·6	85·2	55·8	84·8	89·3	79·6	68·3
COST OF CONSTRUCTION, per mile of line,	£	11269	6092	7792	2995	5330	4,357	7,568
SURPLUS in per cent. of invested capital,	%	5·8	1·10	4·23	1·13	0·57	1·54	4·36

Locomotive Department.

TABLE D.

Railway.	Description				Expenses.													
					Cost of Maintenance						Cost of Working						Sundries, office expenses, gas, wood, &c.		Total	
					Materials for repairs		Wages		Total		Grease, oil, waste, tallow, &c.		Wages of Engineers, Firemen, &c.		Total					
	Gauge	Number of years trafficed	Number of Engines	Total number of engine miles from the beginning	Total	per mile	Total	per mile	Total	per mile	Total	per mile	Total	per mile	Total	per mile	Total	per mile	Total	per mile
					£	d.	£	d.	£	d.	£	d.	£	d.	£	d.	£	d.	£	d.
Christiania-Eidsvold, ..	4′ 8½″	19	23	4,815,550·6	29,527	1·47	33,908	1·69	63,515	3·16	104,495	5·21	41,838	2·08	146,333	7·29	3,701	0·18	213,549	10·68
Lillestróm-Grandsen, ..	4′ 8½″	11																		
Hamar-Aamot, ..	3′ 6″	11	4	376,761	778	0·50	1,095	0·70	1,873	1·20	5,511	3·51	2,825	1·80	8,336	5·31	..	..	10,209	6·51
Throndhjem-Stören, ..	3′ 6″	9	5	438,641	859	0·48	1,292	0·72	2,151	1·20	6,511	3·62	4,399	2·44	10,910	6·06	..	..	13,061	7·26
Drammen-Randsfjord, ..	3′ 6″	5	12	763,616	809	0·25	693	0·22	1,502	0·47	8,291	2·61	4,417	1·39	12,708	4·00	144	0·04	14,354	4·50
Christiania-Drammen, ..	3′ 6″	3	10	788,060															20,460	6·23

Carriage Department.

TABLE E.

Railway	Repairs and Cleaning—Description					Cost	
	Gauge	Number of years trafficed	Number of carriages and wagons	Cost of carriages and wagons	Total number of miles run from the beginning	Cost of repairs and working	
					Total / Per carriage	Total	per mile*
				£		£	*d.*
Christiania-Eidsvold, ...	4′ 8½″	19	412	44,004	62,602,100 / 6381	66,109	0·25
Lillestrøm-Grandsen, ...	4′ 8½″	11	308	35,370			
Hamar-Aamot, ...	3′ 6″	11	64	6,000	2,409,694 / 3730	2597	0·26
Throndhjem-Støren, ...	3′ 6″	9	74	7,000	3,112,739 / 4988	2429	0·18
Drammen-Randsfjord, ...	3′ 6″	5	409	35,555	6,397,815 / 5340	1555	0·18
Christiania-Drammen, ...	3′ 6″	3	204	..	5,079,487 / ..	5361	0·25

* Cost per ton mile not given.—T. F. D.

TABLE F.

Comparative data of the Swedish Government, Christiania, Eidsvold and Stören, Aamot Railways' Carriages.

	Class	Gauge	Number of seats	Length outside	Breadth: Outside	Breadth: Inside: Total	Breadth: Inside: Per seat	Wheel-base	Weight: Total	Weight: Per seat	Cost of carriage: Total	Cost of carriage: Per seat
				Feet	Feet	Feet	Inches	Feet	Tons	Cwt	£	
Swedish Government lines, German pattern, ...	1st.	4′ 8½″	24	19′ 1″	8′ 8″	8′ 0″	2·4″	12′ 0″	5·64	4·70	467	£ s. d.
Do., do., do.,	2nd.		40	22′ 0″	8′ 8″	8′ 0″	19·2″	12′ 0″	6·06	3·03	422	10-11-0
Do., do., do.,	3rd.		40	23′ 1″	8′ 8″	8′ 0″	19·2″	12′ 0″	6·00	3·00	311	7-15-0
Christiania-Eidsvold, English pattern, ...	1st.	4′ 8½″	24	19′ 11″	7′ 9″	7′ 2″	21·5″	10′ 7″	5·6	4·66	444	18-10-0
Do., do., do.,	2nd.		32 & 40	20′ 5″	7′ 9″	7′ 2″	21·5″ & 17·2″	10′ 7″	5·4	3·38&2·70	356	11-2 & 8-18-0
Do., do., do.,	3rd.		32 & 40	20′ 0″	7′ 7″	7′ 2″	21·5″ & 17·2″	11′ 0″	5·35	3·36&2·68	289	9-0 & 7-4·5-0
Stören-Aamot, Narrow-Gauge pattern, ...	1st.	3′ 6″	32	23′ 5″	7′ 0″	6′ 6″	19·5″	11′ 6″	5·2	3·25	322	10-1-0
Do., do., do.,	2nd.		32	20′ 0″	7′ 0″	6′ 6″	19·5″	10′ 0″	4·0	2·5	156	4-17·5-0
Great Western, No. 234 H.	2nd.	4′ 8½″				7′ 0″	21″					
London, North-West, „ 754	2nd.					6′ 9″	20·25″					
Great Northern, „ 311	2nd.					7′ 3″	21·75″					
North-Midland, „ 19	2nd.					6′ 10″	25·5„					

K

TABLE G.

WEIGHT of Wagon compared to the load carried with present material on the Norwegian State Railways on the 4′ 8½″ (i), and the 3′ 6″-gauge (ii), respectively.

	COVERED WAGONS				LOW-SIDED WAGONS				TIMBER AND PLANK WAGONS			
	Wagons weight	Loading capacity	Total weight	Wagon weight to loading capacity*	Wagon weight	Loading capacity	Total weight	Wagon weight to loading capacity*	Wagon weight	Loading capacity	Total weight	Wagon weight to loading capacity*
	Tons.	Tons.	Tons.		Tons.	Tons.	Tons.		Tons.	Tons.	Tons.	
(i) Swedish material,	5·7	7·5	13·2	1 : 1·3	4·8	8·4	13·2	1 : 1·8	4·6	10·5	15·1	1 : 2·3
(ii) Narrow-gauge material, ..	3·7	7·0	10·7	1 : 1·89	3·24	7·0	10·24	1 : 2·16	3·5	7·0	10·5	1 : 2·0

The Locomotive weight (on the driving wheels) on Christiania, Drammen, Randsfjord is 12·85 and 8·0 tons, respectively, for the Larger and Smaller class of engines. The Broad-gauge wagons thus weigh in part as much, and in part even 2·36 tons more, than our largest engines, and 7·1 tons more than the smaller ones, and can therefore not be used on our Narrow-gauge lines unless with heavier rails than hitherto, and are impossible for rails of 30 to 35 lbs. per yard, with the small engines for *minimum traffic*.

* The *useful work* proportion in a unit of time, per wagon, would be altered by using the higher average speed available on (i) the 4′ 8½″ gauge.—T.F.D.

COMPARATIVE weight of Engine required to draw a certain Passenger Train up 1 in 70 on the 3′ 6″- and 4′ 8½″-gauge, respectively.

TABLE H.

3′ 6″-gauge Material: Norwegian Narrow-gauge pattern		4′ 8½″-gauge Material: English Pattern	
4 Composites and 4·6 tons,	18·4 tons	4 Composites, ...	22·4 tons.
8 2nd Class and 3 8 „ ...	30·4 „	4 2nd Class, ...	21·6 „
1 Breakvan, ...	3·8 „	4 3rd „	21·2 „
250 Passengers, ...	18 75 „	1 Breakvan, ...	5·5 „
Luggage, &c., ...	2·00 „	250 Passengers, ...	18·75 „
		Luggage, &c., ...	2·00 „
	73·35 „		91·45 „

Supposing, therefore, this train of 73·36 tons on the Narrow-gauge requires an engine of the standard type on the Christiania, Drammen, Randsfjord line, with a driving wheel pressure of 12·4 tons (total 17 tons), an engine of 16·3 tons on the drivers, say (21·6 total) might be necessary for the 91·45 tons train on the Broad-gauge, or an engine 24 to 25 per cent. heavier.*

COMPARATIVE weight of engine required to draw a certain Goods' train up 1 in 70 on the 3′ 6″- and 4′ 8½″-gauge, respectively.

TABLE I.

	Dramen, Randsfjord, 3′ 6″ gauge		Christiania, Eidsvold 4′ 8½″-gauge. Rolling stock of English Pattern		Swedish Government, 4′ 8½″. Rolling stock of German Pattern	
Average weight of wagon, ...	3·4 tons.		4·4 tons.		4·5 tons.	
„ loading capacity, ...	5·6 „		5·9 „		7·1 „	
Sum, ..	9·0 „		10·3 „		11·6 „	
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Nett load per wagon, ...	3·0	4·5	3·0	4·5	3 0	4·5
„ for 15 wagons,..	45·0	67·5	45·0	67·5	45·0	67·5
Wagon weight for 15 wagons, ...	51·0	51 0	66·0	66·0	67·5	67·5
Sum, ..	96 0	118 5	111·0	133·5	112·5	135·0
Driving wheel pressure for the above named train, ...	13·33	16·46	15·42	18·54	15 62	18 75
Weight for the leading wheels, ...	4·44	5·49	5·14	6·18	5·21	6·25
Weight of locomotive, ...	17·77	21·95	20 56	24·72	20·83	25·0

* For what greater percentage of speed not stated.—T.F.D.

Narrow Gauge Railways—1877.

TABLE K.

Where located	Gauge	Opened and Planned	Projected	Total
	Feet	Miles	Miles	Miles
Norway, ...	3′ 6″	618	..	618
Sweden, ...	2′ 6″—2′ 7″	78	..	..
„	3′ 0″	179	..	..
„	3′ 6—3′ 7″	313	..	..
„	3′ 11″—4′ 0″	133	..	703
Belgium, Ghent, Antwerp, ...	3′ 7″	31	..	31
Germany, Broelthalbahn, ...	2′ 6″	14	..	14
Switzerland, ...	3′ 3″ (1 mte.)	67	81	148
Isle of Man, Tallylyn, ...	2′ 3″	8	..	8
Wales, Festiniog, ...	2 2″	14	..	14
Dinoswick, ...	1′ 11″	..	..	..
France, Tavaux, Pontser's Court, ...	3′ 3″ (1 mte.)	34	..	..
Commentris, Monthicon, ...	3′ 3″ (1 mte.)	20	..	..
Thendalzac, Salles la Source, ...	3′ 3″ (1 mte.)	4	..	58
Sardinia, S. Leoni, ...	2′ 7″	9	..	..
Montessoris, ...	3′ 3″ (1 mte.)	9	..	18
Russia, Livny, ...	3′ 6″	35	..	..
Tchndosa, Novgorod, ...	3′ 6″	46	..	..
Jaroslas, Woloyd, ...	3′ 6″	130	..	211
British Possessions, Queensland, ...	3′ 6″	518	..	..
South Australia, ..	3′ 6″	170	..	..
West Australia, ..	3′ 6″	34	119	..
Cape of Good Hope, ..	3′ 6″	124	..	..
„ „ ..	2′ 6″	93	..	..
Natal, ...	3′ 6″	118	..	..
New Zealand, ...	3′ 6″	1,174	..	..
Tasmania, ...	3′ 6″	121	..	..
East India, ...	3′ 3″ (1 mte.)	789	1,967	..
„ „	4′ 0″	27	..	..
Canada, ...	3′ 6″	1,066	..	5,820
United States of North America, ...	3′ 0″—3′ 6″	2,373	7,951	10,324
Argentin Republic, ...	3′ 3″ (1 mte.)	1,598	2,159	3,757
Chili, Tongry, ...	3′ 6″	..	..	..
Peru, ...	3′ 6″	..	..	..
Brazil, ...	3′ 3″ (1 mte.)	141	..	141
Japan, ...	3′ 6″	140	528	668
Java, ...	3′ 6″	36	..	36
Egypt, Sudan, ...	3′ 6″	552	..	552
	Total,..	10,816	12,805	23,121

No. CCLXI.

DISTRIBUTARY VELOCITY AND DISCHARGE TABLES FOR SIDE SLOPES OF 1 TO 2.

Computed for the N. W. P. Irrigation Department, under superintendence of CAPT. ALLAN CUNNINGHAM, R.E., *Hony. Fell. of King's Coll. Lon.*

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

Data,—

Channel, earthen.
Section, trapezoidal.
Side-slopes of 1 to 2, *i.e.*, $\frac{1 \text{ horizontal.}}{2 \text{ vertical.}}$
b = bed-width *in feet.*
d = depth of water *in feet.*
f = fall of channel in 5,000 feet *in feet.*

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 = Coefficient in formula $V = C\sqrt{RI}$.

Formulæ used in computation.

$$A = \left(b + \frac{d}{2}\right) d \; ; \qquad R = \frac{A}{\quad}$$

$$= \; / \; \cdot 00008533 +$$

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

$$5 \left(\cdot 2438 + \frac{1}{\quad} \right)$$

as *suitable for channels whose* "Bed and Sides are of earth." This formula is simply adapted to English measures from that given by M. Bazin in his "Recherches Expérimentales sur l' écoulement de l'eau dans les canaux découverts."

The Coefficient 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 $U = C \cdot \sqrt{RI}$, whence also

$$V = ($$

[These Table have been prepared throughout 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, and sometimes three, more decimals than are now printed ; and the first differences were examined by the Author himself.

From the regularity of these differences, it is believed that the last figure does not err by more than 2 in any column. A. C.

* Mr. A. Hall and Bábú Hari Singh.

DISTRIBUTARY VELOCITIES AND DISCHARGES.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.														Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 1 foot.																			
3	3·5	·668	·663	2·32	·620	2·17	·574	2·01	·524	1·83	·469	1·64	·406	1·42	·331	1·16	·234	·82	40·52
4	4·5	·722	·711	3·20	·665	2·99	·616	2·77	·562	2·53	·503	2·26	·436	1·96	·356	1 60	·252	1·13	41·87
5	5·5	·760	·746	4·10	·698	3 84	·646	3·55	·590	3·25	·528	2 90	·457	2·51	·373	2·05	·264	1·45	42·80
6	6·5	·789	·773	5·02	·723	4·70	669	4·35	·611	3·97	·546	3·55	·473	3·08	·386	2·51	·273	1 78	43·49
7	7·5	·812	·793	5·95	·742	5·56	·687	5·15	·627	4·70	·561	4·21	·486	3·64	·397	2·97	·280	2·10	44·01
8	8·5	·830	·809	6·88	·757	6 43	·701	5 96	·640	5·44	·572	4·87	·4 6	4·21	·404	3·44	·286	2·43	44·42
9	9·3	·846	·823	7·82	·770	7·31	·713	6·77	·651	6·18	·582	5·53	·504	4·78	·411	3·91	·291	2·76	44·75
10	10·5	·858	·834	8·76	·780	8·19	·723	7·59	·660	6·92	·590	6·19	·511	5·36	·417	4·38	·295	3·10	45·03
11	11·5	·869	·844	9·70	·789	9·08	·731	8·40	·667	7·67	·597	6·86	·517	5·94	·422	4·85	·298	3·43	45·26
12	12·5	·878	·852	10·65	·797	9·96	·738	9·22	·673	8·42	·602	7·53	·522	6·52	·426	5·32	·301	3·76	45·46
13	13·5	·886	·859	11·60	·804	10·85	·744	10 04	·679	9·17	·607	8·20	·526	7·10	·429	5·80	·304	4·10	45·63
14	14·5	·893	·865	12·55	·809	11·73	·749	10·86	·684	9·92	·612	8 87	·530	7·68	·433	6·27	·306	4·44	45·78
15	15·5	·899	·870	13·50	·814	12·62	·754	11·69	·688	10·67	·616	9·54	·533	8·26	·435	6·75	·308	4·77	45·91
16	16·5	·905	·875	14·45	·819	13·51	758	12·51	·692	11·42	·619	10·21	·536	8·85	·438	7·22	·310	5·11	46·02
17	17·5	·910	·880	15·40	·823	14·40	·762	13·33	·696	12·17	·622	10 89	·539	9·43	·440	7·70	·311	5·44	46 12
18	18·5	·914	·884	16·35	·827	15 29	·765	14·16	·699	12·93	·625	11·56	·541	10·01	·442	8·17	·313	5·78	46·22
19	19·5	·918	·887	17·30	·830	16·18	·768	14·98	·702	13·68	·627	12·23	·543	10 59	·444	8·65	·314	6·12	46·30
20	20·5	·922	·891	18·26	·833	17·08	·771	15·81	·704	14·43	·630	12·91	·545	11·18	·445	9·13	·315	6·45	46·38

DISTRIBUTARY VELOCITIES AND DISCHARGES.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.														Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 1·5 feet.																			
3	5·625	·885	·86	4·83	·803	4·52	·743	4·18	·679	3·82	·607	3·41	·526	2·96	·429	2·41	·303	1·71	45·61
4	7·125	·969	·93	6·64	·871	6·21	·807	5·75	·736	5·25	·659	4·69	·571	4·06	·466	3·32	·329	2·35	47·32
5	8·625	1·032	·99	8·51	·923	7·96	·854	7·37	·780	6·73	·697	6·02	·604	5·21	·493	4·25	·349	3·01	48·55
6	10·125	1·082	1·03	10·42	·963	9·75	·891	9·03	·814	8·24	·728	7·37	·630	6·38	·515	5·21	·364	3·68	49·47
7	11·625	1·123	1·06	12·36	·995	11·57	·921	10·71	·841	9·77	·752	8·74	·651	7·57	·532	6·18	·376	4·37	50·18
8	13·125	1·156	1·09	14·33	1·02	13·40	·945	12·41	·863	11·33	·772	10·13	·668	8·77	·546	7·16	·386	5·07	50·76
9	14·625	1·184	1·12	16·31	1·04	15·25	·966	14·12	·881	12·89	·788	11·53	·683	9·98	·557	8·15	·394	5·77	51·23
10	16·125	1·207	1·13	18·30	1·06	17·11	·983	15·85	·897	14·46	·802	12·94	·695	11·20	·567	9·15	·401	6·47	51·63
11	17·625	1·228	1·15	20·30	1·08	18·98	·997	17·58	910	16·04	·814	14·35	·705	12·43	·576	10·15	·407	7·18	51·96
12	19·125	1·246	1·17	22·30	1·09	20·86	1·01	19·32	·922	17·63	·825	15·77	·714	13·66	·583	11·15	·412	7·89	52·25
13	20·625	1·261	1·18	24·32	1·10	22·75	1·02	21·06	·932	19·22	·834	17·19	·722	14·89	·590	12·16	·417	8·60	52·50
14	22·125	1·275	1·19	26·34	1·11	24·64	1·03	22·81	·941	20·82	·842	18·62	·729	16·13	·595	13·17	·421	9·31	52·72
15	23·625	1·287	1·20	28·36	1·12	26·53	1·04	24·56	·949	22·42	·849	20·05	·735	17·37	·600	14·18	·424	10·03	52·91
16	25·125	1·298	1·21	30·39	1·13	28·43	1·05	26·32	·956	24·02	·855	21·49	·741	18·61	·605	15·19	·428	10·74	53·08
17	26·625	1·308	1·22	32·42	1·14	30·33	1·05	28·08	·963	25·63	·861	22·92	·746	19·85	·609	16·21	·431	11·46	53·23
18	28·125	1·317	1·23	34·45	1·15	32·23	1·06	29·84	·969	27·24	·866	24·36	·750	21·10	·613	17·23	·433	12·18	53·37
19	29·625	1·325	1·23	36·49	1·15	34·13	1·07	31·60	·974	28·85	·871	25·80	·754	22·35	·616	18·24	·436	12·90	53·51
20	31·125	1·333	1·24	38·53	1·16	36·04	1·07	33·36	·979	30·46	·875	27·24	·758	23·59	·619	19·26	·438	13·62	53·61

DISTRIBUTARY VELOCITIES AND DISCHARGES.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.														Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 2 feet.																			
3	8·00	1·071	1·02	8·15	·953	7·63	·883	7·06	·806	6·45	·72	5·77	·62	4·99	·51	4·08	·36	2·88	49·26
4	10·00	1·180	1·11	11·12	1·04	10·40	·963	9·63	·879	8·79	·79	7·86	·68	6·81	·56	5·56	·39	3·93	51·17
5	12·00	1·267	1·18	14·21	1·11	13·29	1·03	12·30	·936	11·23	·84	10·05	·73	8·70	·59	7·10	·42	5·02	52·59
6	14·00	1·337	1·24	17·38	1·16	16 25	1·08	15·05	·98	13 74	·88	12·29	·76	10·64	·62	8·69	·44	6·14	53·67
7	16·00	1·395	1·29	20·61	1·21	19·28	1·12	17·85	1·02	16·29	·91	14·57	·79	12·62	·64	10·30	·46	7·29	54·53
8	18·00	1·443	1 33	23·89	1·24	22·34	1·15	20·69	1·05	18·88	·94	16·89	·81	14·63	·66	11·94	·47	8·45	55·23
9	20 00	1·485	1·36	27·20	1·27	25·44	1·18	23·55	1·08	21·50	·96	19·23	·83	16.66	·68	13·60	·48	9·62	55·81
10	22 00	1·520	1·39	30·54	1·30	28·57	1·20	26·45	1·10	24·14	·98	21·50	·85	18·70	·69	15·27	·49	10·80	56·29
11	24·00	1·551	1·41	33·90	1·32	31·71	1·22	29·36	1·12	26·86	1·00	23 97	·87	20·76	·71	16·95	·50	11·99	56·71
12	26·00	1·578	1·43	37·28	1·34	34·87	1·24	32·29	1·13	29·47	1·01	26·36	·88	22·83	·72	18·64	·51	13·18	57·07
13	28·00	1·603	1·45	40·67	1·36	38·05	1·26	35·23	1·15	32·16	1·03	28·76	·89	24·91	·73	20·34	·51	14·38	57·38
14	30·00	1·624	1·47	44·08	1·38	41·24	1·27	38·18	1·16	34 85	1·04	31·17	·90	27·00	·74	22·04	·52	15·59	57·65
15	32 00	1·643	1·48	47·50	1·39	44 43	1·29	41·14	1·17	37·55	1·05	33·59	·91	29·09	·74	23·75	·53	16·80	57·90
16	34·00	1·66	1·50	50·93	1·40	47·64	1·30	44·11	1·18	40·26	1 06	36·01	·93	31·09	·75	25·46	·53	18 01	58·12
17	36·00	1·677	1·51	54·36	1·41	50·85	1·31	47·08	1·19	42·98	1·07	38·44	·93	33·29	·76	27·18	55	19·22	58·31
18	38·00	1·691	1·52	57·80	1·42	54·07	1·32	50·06	1·20	45·70	1·08	40·87	·93	35·40	·76	28·90	·54	20.44	58·43
19	40·00	1·704	1·53	61·25	1·43	57·29	1·33	53·04	1·21	48·42	1·08	43·31	·94	37·51	·77	30·62	·54	21·66	58·65
20	42·00	1·716	1·54	64·70	1·44	60·52	1 33	56 03	1·22	51·15	1·09	45·76	·94	39 62	·77	32·35	·55	22·88	58·80

DISTRIBUTARY VELOCITIES AND DISCHARGES.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.																Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 2·5 feet.																			
3	10·625	1·237	1·16	12·32	1·08	11·52	1·00	10·66	·92	9·74	·82	8·70	·71	7·54	·58	6·16	·41	4·35	52 11
4	13·125	1·369	1·27	16·63	1·19	15·55	1 10	14·40	1 00	13·15	·90	11·76	·78	10·18	·63	8·31	·45	5·88	54·15
5	15·625	1·475	1·35	21·14	1·27	19·77	1·17	18·30	1·07	16·71	·96	14·95	·83	12·94	·68	10·57	·48	7 47	55·68
6	18·125	1·564	1·42	25·78	1·33	24·12	1·23	22·33	1·13	20·38	1·01	18·23	·87	15·79	·71	12 89	·50	9·12	56·88
7	20·625	1·638	1·48	30·53	1 39	28·56	1 28	26·44	1·17	24·14	1·05	21·59	·91	18·70	·74	15·27	·52	10·80	57·83
8	23·125	1·702	1·53	35·37	1·43	33·08	1·32	30·63	1·21	27·96	1·08	25·01	·94	21·66	·77	17·68	·54	12·50	58 62
9	25·625	1·756	1·57	40.26	1·47	37·66	1·36	34·87	1·24	31·83	1·11	28·47	·96	24·65	·79	20·13	·56	14·23	59·28
10	28·125	1·804	1 61	45·20	1·50	42·28	1·39	39·15	1·27	35·74	1·14	31·96	·98	27·68	·80	22·60	·57	15·98	59·83
11	30 625	1·846	1·64	50·19	1·53	46·95	1·42	43·46	1·30	39·68	1·16	35·49	1·00	30·73	·82	25·09	·58	17·74	60·31
12	33·125	1·883	1·67	55·21	1·56	51·64	1·44	47·81	1·32	43·64	1·18	39·04	1·02	33·81	·83	27·60	·59	19·52	60·72
13	35·625	1·916	1·69	60·25	1·58	56·36	1·47	52·18	1·34	47·63	1 20	42·61	1·04	36·90	·85	30·13	·60	21·30	61·14
14	38·125	1·946	1 71	65 32	1·60	61·10	1·48	56·57	1·36	51·64	1·21	46·19	1 05	40·00	·86	32 66	·61	23·09	61 41
15	40·625	1·973	1·73	70·41	1·62	65·86	1·50	60·98	1 37	55·67	1·23	49·79	1·06	43·12	·87	35·20	·61	24·89	61·70
16	43·125	1 997	1·75	75·52	1·64	70·64	1·52	65·40	1·38	59·70	1 24	53·40	1·07	46·25	.88	37·76	·62	26·70	61·95
17	45·625	2·020	1·77	80·64	1·65	75·43	1·53	69·83	1·40	63·75	1·25	57·02	1·08	49 38	.88	40·32	·63	28·51	62·18
18	48·125	2·040	1 78	85·77	1 67	80·23	1 54	74·28	1·41	67·81	1·26	60 65	1·09	52·52	.89	42·89	·63	30·32	62·39
19	50·625	2·059	1·80	90·92	1.68	85·04	1·56	78·74	1·42	71 88	1·27	64·29	1·10	55·67	·90	45·46	·64	32·14	62·59
20	53·125	2·076	1·81	96·07	1·69	89·87	1·57	83·20	1·43	75·95	1·28	67·93	1·11	58·83	·90	48·04	·64	33·97	6276

DISTRIBUTARY VELOCITIES AND DISCHARGES.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.																Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 3 feet.																			
3	13·5	1·391	1·29	17·34	1·20	16·22	1·11	15·02	1·02	13·71	·91	12·26	·79	10·62	·64	8·67	·45	6·13	54·47
4	16·5	1·541	1·40	23·17	1·31	21·68	1·22	20·07	1·11	18·32	·99	16 39	·86	14·19	·70	11·59	·50	8 19	56·57
5	19·5	1·665	1·50	29·28	1·41	27·39	1·30	25 36	1·19	23·15	1·06	20·70	·92	17 93	·75	14·64	·53	10·35	58·18
6	22·5	1·771	1·58	35·59	1·48	33·29	1·37	30·82	1·25	28·14	1·12	25·17	97	21·80	·79	17·80	·56	12·55	59·44
7	25·5	1·860	1·65	42·06	1·54	39 35	1·43	36 43	1·30	33·25	1·17	29·74	1·01	25·76	·83	21·03	·58	14·87	60·47
8	28·5	1·938	1·71	48·65	1·60	45·51	1·48	42·13	1·35	38·46	1 21	34·40	1·05	29·79	·85	24·33	·60	17·20	61·32
9	31·5	2·005	1·76	55·34	1·64	51·77	1·52	47·93	1·39	43·75	1·24	39·13	1·08	33·89	·88	27·67	·62	19·57	62·03
10	34·5	2·065	1·80	62·11	1·68	58·10	1·56	53·79	1·42	49·10	1·27	43·92	1·10	38·03	·90	31·05	·64	21·96	63 64
11	37·5	2·118	1·84	68·94	1·72	64·49	1·59	59·71	1 45	54·51	1·30	48·75	1·13	42·22	·92	34·47	·65	24·38	63·17
12	40·5	2·165	1·87	75·83	1·75	70·93	1·62	65 67	1·48	59 95	1·32	53·62	1·15	46·44	·94	37·91	·66	26·81	63·63
13	43·5	2·207	1·90	82·76	1·78	77·42	1·65	71·67	1·50	65·43	1·35	58·52	1·17	50 68	·95	41·38	·67	29·26	64 03
14	46·5	2 245	1·93	89·73	1·81	83·94	1·67	77·71	1·53	70·94	1·36	63·45	1·18	54·95	·97	44·87	·68	31·72	64·39
15	49·5	2·280	1·95	96·74	1·83	90·49	1·69	83·78	1·55	76·48	1·38	68·40	1·20	59·24	·98	48·37	·69	34·20	64·71
16	52·5	2·312	1·98	103·77	1·85	97·07	1·71	89·87	1·56	82·04	1·40	73·37	1 21	63·54	·99	51·88	·70	36·69	65·00
17	55 5	2·341	2·00	110 82	1·87	103·67	1·73	95·98	1·58	87·61	1·41	78·36	1·22	67·86	1·00	55·41	·71	39·18	65·26
18	58·5	2·368	2·02	117·90	1·89	110·29	1 75	102·11	1·59	93·21	1·43	83·37	1·23	72·20	1·01	58·95	·71	41·68	65·49
19	61·5	2·392	2·03	125·00	1·90	116·92	1·76	108·25	1·61	98·82	1·44	88·39	1·24	76·55	1·02	62·50	·72	44·19	65·70
20	64·5	2·415	2·05	132·11	1·92	123·57	1·77	114·41	1·62	104·44	1·45	93·42	1·25	80·90	1·02	66·06	·72	46·71	65·92

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.																Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 3·5 feet.																			
3	16·625	1·536	1·40	23·28	1·31	21·78	1·21	20·16	1·11	18·46	·990	16·46	·858	14·26	·700	11·64	495	8·23	56·50
4	20·125	1·702	1·53	30·78	1·43	28·79	1·33	26·66	1·21	24 34	1·08	21·76	·937	18·85	·765	15·39	541	10 88	58·62
5	23·625	1·842	1·64	38·64	1·53	36·15	1·42	33·47	1·29	30·55	1·16	27·33	1·00	23·67	·818	19·32	·578	13·66	60·26
6	27·125	1·962	1·73	46·79	1·61	43·77	1·49	40·52	1·36	36·99	1·22	33·08	1·06	28·65	863	23·40	·610	16·54	61·58
7	30·625	2·066	1·80	55·15	1·69	51·59	1·56	47·76	1·42	43·60	1·27	39·00	1·10	33 77	·900	27·58	·637	19·50	62·65
8	34·125	2·156	1·87	63·68	1·75	39·57	1·62	55·15	1·48	50·35	1·32	45·03	1·14	39·00	·933	31·84	·660	22 52	63·55
9	37·625	2·236	1·92	72·35	1·80	67·68	1·67	62·66	1·52	57·20	1·36	51·16	1·18	44·31	·962	36·18	·680	25·58	64·30
10	41·125	2·307	1·97	81·14	1·85	75·90	1·71	70·27	1·56	64·15	1·40	57·38	1·21	49 69	·987	40·57	·698	28 68	64·95
11	44·625	2·370	2·02	90·02	1·89	84·21	1·75	77·96	1·60	71·17	1·43	63·66	1·24	55·13	1·01	45·01	·713	31·83	65·51
12	48·125	2·427	2·06	98·98	1·92	92·59	1·78	85·72	1·63	98·25	1·45	69·99	1·26	60·61	1·03	49·49	·727	35·00	66 01
13	51·625	2·479	2·09	108·01	1·96	101·03	1·81	93·54	1 65	85·39	1·48	76·37	1·28	66·14	1·05	54·00	·740	38·19	66·44
14	55·125	2·526	2·12	117·09	1·99	109·53	1·84	101·40	1·68	92·57	1·50	82·80	1·30	71·70	1·06	58·55	·751	41 40	66·83
15	58·625	2·568	2·15	126·23	2·01	118·07	1·87	109·31	1·70	99·79	1·52	89·25	1·32	77 30	1·08	63·11	·761	44·63	67·18
16	62·125	2·607	2·18	135·40	2·04	126·66	1·89	117·26	1·72	107 04	1·54	95·74	1·34	82·92	1·09	67·70	·771	47·87	67·49
17	65·625	2·643	2·20	144·61	2·06	135·27	1·91	125 24	1·74	114 33	1·56	102·26	1·35	88·57	1·10	72·31	·779	51·13	67·77
18	69·125	2·677	2·23	153 86	2·08	143·92	1·93	133·25	1·76	121·64	1·57	108·80	1·36	94·23	1·11	76·93	·787	54·49	68·03
19	72·625	2·707	2·25	163·14	2·10	152·60	1·95	141·28	1·78	128 97	1·59	115 36	1·38	99·91	1·12	81·57	·794	57·68	68·26
20	76·125	2·736	2·27	172·44	2·12	161·30	1·96	149·34	1·79	136·32	1·60	121 93	1·39	105·60	1·13	86·22	·801	60·97	68 48

DISTRIBUTARY VELOCITIES AND DISCHARGES.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.																Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 4 feet.																			
3	20·00	1·674	1·51	30·17	1·41	28·22	1·31	26·13	1·19	23 85	1·07	21·33	·924	18·47	·754	15·08	·53	10·67	58·29
4	24·00	1·854	1·65	39·48	1·54	36·93	1·42	34·19	1·30	31·21	1·16	27·92	1·01	24·18	·822	19·74	·58	13·96	60·40
5	28·00	2·008	1·76	49·25	1·65	46·07	1·52	42·65	1·39	38·93	1·24	34·82	1·08	30·16	·88	24·62	·62	17·41	62·06
6	32·00	2·141	1·86	59·38	1·74	55·54	1·61	51·42	1·47	46·94	1·31	41·99	1·14	36·36	·93	29·69	·66	20·99	63·40
7	36·00	2·258	1·94	69·79	1·81	65·28	1·68	60·44	1·53	55·17	1·37	49 35	1·19	42·73	·97	34·89	·69	24·67	64·50
8	40·00	2·361	2·01	80·42	1·88	75·23	1·74	69·65	1·59	63·58	1·42	56·87	1·23	49·25	1·01	40·21	·71	28·43	65·43
9	44·00	2·452	2 07	91·25	1·94	85·35	1·80	79 02	1·64	72·14	1·47	64·52	1·27	55·87	1·04	45·62	·73	32·26	66·22
10	48·00	2·534	2·13	102·22	1·99	95·62	1·84	88·53	1·68	80·81	1·51	72·28	1·30	62·60	1·06	51·11	·75	36·14	66·90
11	52·00	2·607	2·18	113·33	2·04	106·01	1·89	98·15	1·72	89·59	1·54	80·13	1·33	69·40	1·09	56·66	·77	40·07	67·49
12	56·00	2·674	2·22	124·54	2 08	116·50	1·93	107·86	1·76	98·46	1·57	88·07	1·36	76·27	1·11	62·27	·79	44·03	68·00
13	60·00	2·734	2·26	135·85	2·12	127·08	1·96	117·65	1·79	107·40	1·60	96·06	1·39	83·19	1·13	67·93	·80	48·03	68·46
14	64·00	2·789	2·30	147·24	2·15	137·73	1·99	127·51	1·82	116·40	1·63	104·11	1·41	90·16	1·15	73·62	·81	52·06	68·87
15	68·00	2·840	2·33	158·70	2·18	148·45	2·02	137·43	1·85	125·46	1·65	112·21	1·43	97·18	1·17	79·35	·83	56·11	69.24
16	72·00	2·886	2·36	170·21	2 21	159·22	2·05	147·41	1·87	134·56	1·67	120·36	1·45	104·23	1·18	85·11	·84	60·18	69·57
17	76·00	2·929	2·39	181·78	2·24	170·04	2·07	157·43	1·89	143·71	1·69	128·54	1·47	111·32	1·20	90·89	·85	64·27	69.88
18	80·00	2·969	2·42	193·40	2·26	180·91	2·09	167·49	1·91	152·89	1·71	136 75	1·48	118·43	1·21	96·70	·85	68·38	70·15
19	84·00	3·006	2·44	205·06	2·28	191·82	2·11	177·59	1·93	162·11	1·73	145·00	1·49	125·57	1·22	102·53	·86	72·50	70.40
20	88·00	3·040	2·46	216·76	2·30	202·76	2·13	187·72	1·95	171·36	1·74	153·27	1·51	132·74	1·23	108·38	·87	76·63	70·63

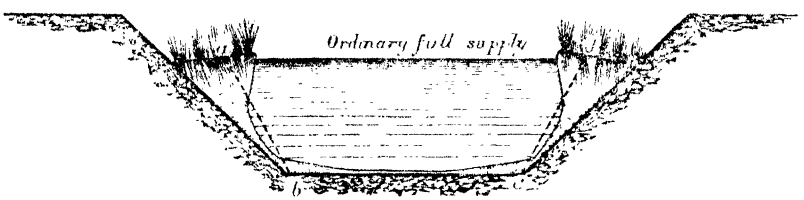
Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.														Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 4·5 feet.																			
3	23·625	1·809	1·61	38·05	1·51	35·60	1·40	32·95	1·27	30·08	1·14	26·91	·99	23·30	·81	19·03	·57	13·45	59·89
4	28·125	2·000	1·75	49·30	1·64	46·12	1·52	42·70	1·39	38·98	1·24	34·86	1·07	30·19	·88	24·65	·62	17·43	61·98
5	32·625	2·166	1·87	61·11	1·75	57·17	1·62	52·92	1·48	48·31	1·32	43·21	1·15	37·42	·94	30·56	·66	21·61	63·64
6	37·125	2·311	1·98	73·36	1·85	68·62	1·71	63·53	1·56	58·00	1·40	51·87	1·21	44·93	·99	36·68	·70	25·94	64·99
7	41·625	2·440	2·07	85·96	1·93	80·41	1·79	74·45	1·63	67·96	1·46	60·79	1·27	52·64	1·03	42 98	·73	30·39	66·11
8	46·125	2·554	2·14	98·85	2·01	92·47	1·86	85·61	1·69	78·15	1·52	69·90	1·31	60·53	1·07	49·43	·76	34·95	67·06
9	50·625	2·656	2·21	111·98	2·07	104·75	1·92	96·98	1·75	88·53	1·56	79·18	1·36	68·57	1·11	55·99	·78	39·59	67·87
10	55·125	2·748	2·27	125·30	2·13	117·21	1·97	108·52	1·80	99·06	1·61	88·60	1·39	76·73	1·14	62·65	·80	44·30	68·57
11	59·625	2·831	2·33	138·80	2·18	129·83	2·02	120 20	1·84	109·73	1·65	98·14	1·43	85·00	1·16	69·40	·82	49 07	69·18
12	64·125	2·907	2·38	152·43	2·22	142·59	2·06	132·00	1·88	120·51	1·68	107·79	1·46	93·35	1·19	76·22	·84	53·89	69·72
13	68·625	2·976	2·42	166·19	2·27	155·46	2·10	143·92	1·91	131·38	1·71	117·51	1·48	101·77	1·21	83 09	·86	58·76	70·20
14	73·125	3·039	2·46	180·05	2 30	168 42	2·12	155·93	1·95	142·34	1·74	127·32	1 51	110·26	1·23	90 03	·87	63·66	70·62
15	77·625	3·097	2·50	194·01	2·34	181·48	2·16	168·02	1·98	153 38	1·77	137·19	1·53	118·81	1·25	97·00	·88	68·59	71·01
16	82·125	3·151	2·53	208·05	2·37	194·61	2·19	180·17	2·00	164·48	1·79	147·11	1·55	127·40	1·27	104 02	·90	73·56	71·36
17	86·625	3·201	2·56	222·16	2·40	207·81	2·22	192·39	2·03	175 63	1·81	157·09	1·57	136·04	1·28	111·08	·91	78·54	71·67
18	91·125	3·247	2·59	236·33	2·43	221·07	2·25	204·67	2·05	186·83	1·83	167·11	1·59	144·72	1·30	118·16	·92	83·55	71·96
19	95·625	3·290	2·62	250·56	2·45	234·38	2·27	216·99	2·07	198·08	1·85	177·17	1·61	153·44	1·31	125·28	·93	88·59	72·23
20	100·125	3·331	2·63	264·84	2·47	247·73	2·29	229·36	2·09	209·37	1·87	187·27	1·62	162·18	1·32	132·43	·94	93·64	72·47

DISTRIBUTARY VELOCITIES AND DISCHARGES.

Bed Width.	Area of water section.	Mean Hydraulic depth.	Fall of Channel in 5,000 feet.																Coefficient C.
			2·00		1·75		1·50		1·25		1·00		0·75		0·50		0·25		
			V	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	
Side slopes, 1 to 2. Depth of water, 5 feet.																			
3	27·5	1·939	1·71	46·98	1·60	43·95	1·48	40·69	1·35	37·14	1·21	33·22	1·05	28·77	·854	23·49	·604	16·61	61·34
4	32·5	2·141	1·86	60·30	1·74	56·40	1·61	52·22	1·47	47·67	1·31	42·64	1·14	36·92	·928	30·15	·656	2 132	63·40
5	37·5	2·318	1·98	74·27	1·85	69·47	1·72	64·32	1·57	58·72	1·40	52·52	1·21	45 48	·990	37·14	·700	26·26	65·05
6	42·5	2·474	2·09	88·77	1·95	83·04	1·81	76·88	1·65	70·18	1·48	62·77	1·28	54·36	1·04	44·38	·758	31·39	66 40
7	47·5	2·613	2·18	103·70	2·04	97·00	1 89	89·80	1·73	81·98	1·54	73·32	1·34	63·50	1 09	51 85	·772	36·66	67·53
8	52·5	2·737	2·27	118·97	2·12	111·29	1·96	103·03	1·79	94·06	1·60	84·13	1·39	72·85	1·13	59·49	·801	42·06	68·49
9	57·5	2·849	2·34	134·54	2·19	125·85	2 03	116·52	1·85	106 37	1·66	95·14	1·43	82·39	1·17	67·27	·827	47·57	69·31
10	62·5	2·951	2·41	150·35	2·25	140 65	2·08	130 22	1·90	118 87	1·70	106 32	1·47	92·08	1·20	75·18	·851	53·16	70 02
11	67·5	3·043	2·47	166·39	2·31	155·64	2·14	144·10	1·95	131·54	1·74	117·65	1·51	101·89	1·23	83·19	·872	58·83	70·65
12	72·5	3·128	2·52	182·59	2·36	170·80	2·18	158·13	1·99	144·35	1·78	129·11	1·54	111·82	1·26	91·30	·890	64·56	71·21
13	77·5	3·205	2·57	198·96	2·40	186·11	2·22	172·30	2·03	157·29	1·82	140·68	1·57	121·84	1·28	99·48	·908	70·34	71·70
14	82·5	3·276	2·61	215·45	2·44	201·54	2·26	186·59	2 07	170·33	1 85	152·35	1·60	131·94	1·31	107·73	·923	76·17	72·14
15	87·5	3·342	2·65	232·07	2·48	217·03	2·30	200·98	2·10	183·47	1·88	164·10	1·62	142·11	1·33	116·04	·938	82·05	72·54
16	92·5	3·403	2·69	248·79	2·52	232 72	2·33	215·46	2·13	196 69	1·90	175·92	1·65	152·35	1·35	124·40	·951	87 96	72·90
17	97·5	3·460	2·72	265·61	2·55	248·45	2·36	230·02	2·15	209·98	1·93	187 81	1·67	162·65	1·36	132·80	·963	93·91	73·23
18	102·5	3·513	2·76	282·50	2·58	264·26	2·39	244·65	2·18	223·34	1·95	199·76	1·69	172 99	1·38	141·25	·974	99·88	73·53
19	107·5	3·562	2·79	299·47	2·61	280·13	2·41	259·35	2·20	236·75	1·97	211·76	1·71	183·39	1·39	149·74	·985	105·88	73·80
20	112·5	3·608	2·81	316·51	2·63	296·06	2·44	274·10	2·22	250·20	1·99	223·80	1·72	193·82	1·41	158·25	·995	111·90	76 06

Note by Major W. Jeffreys, R.I

are divided as to the pitch with which the inner slopes of Distributaries should be made. In the Punjab a slope of 1½ to 1 is adopted, while in North West Provinces 1 to 1 is preferred, chiefly for economical reasons. For very light soils, the former of these is of course the stronger construction, but an officer of irrigation experience is able to distinguish between a rajbaha newly made, and one that has settled down into an irrigating line. Whatever slope is adopted in construction, it is found that this cannot be advantageously maintained after the channel has been in use for some time. A distributary at the close of an irrigating season invariably assumes the following shape, except when the soil is impregnated with *reh*. When the time for clearance comes round, the



Engineer in charge, if he is wise, will not attempt to restore the original section which is opposed to the form that nature adopts. It is only waste of money to dig away the long slopes which are soon re covered with silt, while in theory it does not afford a maximum hydraulic depth which it is the great object to attain in channels with low velocities. The custom on Ganges Canal Distributaries is to trim off the slope at ½ to 1, as shown by thick dotted lines *ab*, *cd*, in the figure; and this in practice is found to conform more closely to the average working section than any other. To arrive then approximately at any thing like the working results, the discharge tables employed by the rajbaha designer should be based on these conditions.

The foregoing is intended to explain the reason for introducing the present set of Tables.

W. J.

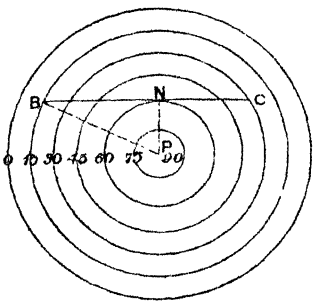
No. CCLXII.

THE GREAT CIRCLE TRACK.

By Capt. H. Wilberforce Clarke, R.E.

In works on Spherical Trigonometry, it is proved that the arc of a* Great Circle passing through any two points is shorter than any other arc, passing through the same two points, on the same sphere.

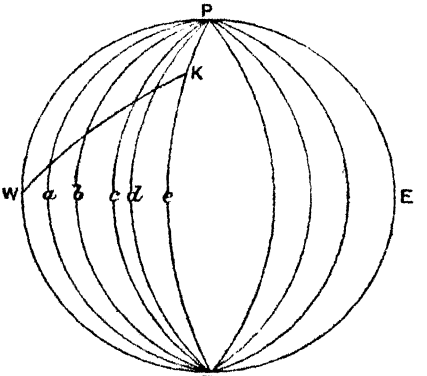
Fig. 1.



This being the case, the shortest distance between any two places A, B on the surface of the earth is the arc of the Great Circle intercepted between them.

Hence, the arc of a Great Circle is the course which one ought to pursue, whether travelling on the Ocean, on the Railway, or on the Road, unless other considerations, —such as currents, winds, rocks or towns, rivers,— render it expedient to deviate from it.

Fig. 2.



Unless one is moving due North, South, East or West, the course of the Great Circle is one which constantly changes its direction, with regard to the meridian. Thus in *Fig.* 2. The arc, WK, of a Great

* A Great Circle is the circle described on the surface of a sphere, by a plane which passes through the centre of the

Circle, between two places W and K, cuts the meridians PaP_1, PbP_1, PcP_1, successively at an angle, ever varying.

The labour involved in discovering the angle at which the arc of the Great Circle cuts the meridians successively, was, and is still, one of the chief reasons why this course is not pursued, when circumstances are favourable to it.

It is manifest, however, that a table or a chart embracing every variation might be made, by reference to which, the angle could, at once, be learned.

This has been done by Mr. Hugh Godfray, in his Chart for facilitating Great-Circle-Sailing.

The method which is pursued is as follows :—

At the South Pole,—for there, there is the largest expanse of water, —suppose a plane to be dropped touching the pole, and perpendicular to the axis of the earth: the parallels of latitude will then, if the eye be supposed at the earth's centre, be projected, on this plane, in circles, while a great circle will, every where, be a straight line.

This projection is called Gnomonic; it, evidently, suffers great distortion a few degrees distant from the pole.

Fig. (1) represents the parallels of latitude thus projected. Suppose B, C, to be two places on the earth's surface, projected on this plane; join BC; then the straight line BC is the Great Circle track between the two places. It will be observed, from an inspection of *Fig.* 1, that the latitude of B is 15° while the highest latitude reached by the straight line is 60° at N.

Draw the dotted lines NP, BP; then is BNP the projection, on the plane, of the spherical triangle, on the surface of the earth.

Since, NP and BP are straight lines, on this plane, they are arcs of Great Circles, on the sphere.

Hence, in the spherical triangle (of which BNP is the projection) right-angled at N we have :—

Supposing ϕ = latitude of B

,, ψ = latitude of N

,, θ = NBP = direction of course BC to the* meridian passing through B.

* The meridian of a place is the Great Circle passing through the Zenith of the place and the pole of the earth.

By Napier's Rules,

$$\sin NP = \cos \overline{\frac{\pi}{2} - \theta} . \cos \overline{\frac{\pi}{2} - BP} = \sin \theta . \sin BP$$

$$\sin \overline{90 - \psi} = \sin \theta . \sin \overline{90 - \phi} = \sin \theta . \cos \phi$$

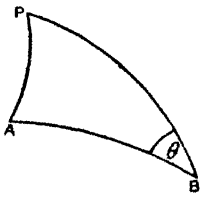
$$\therefore \sin \theta = \frac{\cos \psi}{\cos \phi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1),$$

from which θ may be determined.

It will be noticed that ψ will remain unchanged. The value of θ depending on the value of ϕ as the ship B approaches N, coincides with N, or moves towards C.

Let in *Fig* 3, P be the pole; A, B any two places on the Great Circle Track, A having the highest latitude ψ.

Fig. 3.



Let $PA = \overline{90 - \psi}$

Let $AB = d$ miles $= \frac{d}{60}$ degrees.

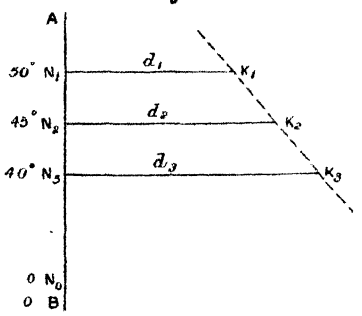
Then, in the right-angled triangle PAB, we have:—

$$\sin AB = \tan PA . \tan \overline{\frac{\pi}{2} - \theta} = \cot \psi . \cot \theta$$

$$\therefore \sin \frac{d}{60} = \cot \psi . \cot \theta \ldots\ldots\ldots\ldots (2).$$

This gives the connexion between the distance (from the highest latitude at A) and the course θ.

Fig. 4.

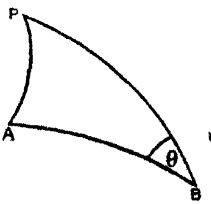


Thus, in *Fig.* 4, draw AB vertically and N_1K_1 perpendicularly to AB; then, if N_1K_1 be drawn where the highest latitude is 50° and we assume θ to have a value of 5 points, we obtain a value for N_1K_1. Similarly, values of N_2K_2; N_3K_3; &c., may be obtained.

A Line through these points gives the curve for the course θ.

Let in *Fig.* 5, P be the pole; A, B two places on Great Circle Track, of which A has the highest latitude ψ.

Fig. 5.



Let $PA = \overline{90 - \psi}$

Let $PB = \overline{90 - \phi}$

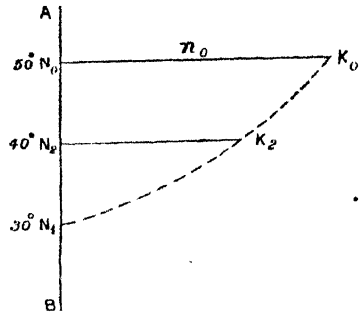
Let $AB = (n)$ miles $= \frac{n}{60}$ degrees.

Then $\sin \overline{90 - PB} = \cos PA . \cos AB = \sin \psi . \cos \frac{n}{60}$

$$\therefore \cos \frac{n}{60} = \sin \phi . \operatorname{cosec} \psi \ldots\ldots (3).$$

Equation (3) determines the distance, at which the "Latitude curve" ϕ crosses the horizontal line ψ.

Fig. 6.



Thus, in *Fig.* 6, draw AB, vertically; and N_0K_0 perpendicularly to it.

Suppose $\psi = 50°$ and $\phi = 30$.

Then N_0K_0 will be determined by equation 3 and K_0 will be a *point* in the latitude curve.

By giving different values to the curve can be traced out.

The curves should be worked out for every degree.

Thus, highest latitude $\psi = 90°$; and lowest latitude $\phi = 20°$,

" " " $\psi = 90°$ " " $\varphi = 21°$,

" " " $\psi = 90°$ " " $\phi = 22°$,

and so on.

The Diagram is constructed by applying *Fig.* 6 to *Fig.* 4.

Then, supposing the highest latitude ψ to be 50° and lowest latitude (or that of the position of the ship) to be 30°.

The line K_0N_0 will represent the course in direction and length of the ship.

And *Fig.* 6 being applied to *Fig.* 4, this line K_0N_0 will cut successively the lines similar to K_1 K_2 K_3, in *Fig.* 4.

At the points of intersection, the course will be that determined by the value of θ for the curved line, similar to K_1 K_2 K_3 in *Fig.* 4.

It has been observed that the Gnomonic Projection becomes much distorted in low latitudes.

But, this is of little importance, because:—

(1). The Trade-Winds—to which every method of sailing must be subservient—blow between the parallels 0° and 25°, on either side of the Equator.

(2). The difference is hardly sensible, near the Equator, between the Track by the Great Circle and those courses determined by Mercator, Middle-Latitude, and Plane Sailing.

At the same time, it may be remarked, that the point of contact, be-

tween the Plane and the Sphere, may be chosen in the Equator, or a little on one side.

(a). If the point of contact be in the Equator :

The meridians will be represented as straight lines, and parallels of Latitude as Hyperbolas.

(b). If the point of contact be not in the Equator :

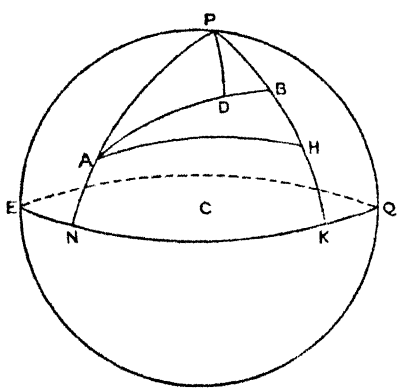
The meridians would be represented as converging straight lines, and the parallels of Latitude as Hyperbolas and Ellipses.

For further information regarding Great-Circle-Sailing, the Reader is referred to a Chart and Diagram for facilitating Great-Circle-Sailing, —with Pamphlet thereon,—by Hugh Godfray, M. A., St. John's College, Cambridge University ; and published by S. D. Potter, 31 Poultry, London, Agent for the Admiralty-Charts.

By means of *Fig.* 7 we can, at the expense of some labour, dispense with the use of the Gnomonic-Projection,—if we are assured, that no dangers, such as rocks or shoals lie in the course.

Let A, B be two places, on the surface of the earth.

Fig 7.



Let ϕ = latitude of A = AN
ϕ' = „ B = BK
l = longitude of A $\}$ ∴ NK
l_1 = „ B $\}$ = $(l_1 - l)$.

Suppose AB to be an arc of a Great Circle passing through A and B.

Then the arc AB is the Great-Circle-Track between the two places.

Let a Great Circle pass through A, cutting PK in H, so that KH = NA; draw PD perpendicular to AB.

In the $\triangle$ APH :

$$\cos AH = \cos AP \cdot \cos PH + \sin AP \cdot \sin PH \cdot \cos P,$$
$$= \cos^2 AP + \sin^2 AP \cdot \cos (l_1 - l)$$
$$\therefore \cos AH = \sin^2 \phi + \cos^2 \phi \cdot \cos (l_1 - l) \ldots\ldots\ldots\ldots (1).$$

$$\sin AH : \sin AP :: \sin P : \sin AHP,$$

$$\therefore \sin AHP = \sin P \cdot \frac{\sin AP}{\sin AH} = \sin (l_1 - l) \cdot \frac{\cos \phi}{\sin AH} \ldots\ldots (5).$$

In the $\triangle$ ABH:

$$\cos AB = \cos BH \cdot \cos AH + \sin BH \cdot \sin AH \cdot \cos AHP =$$
$$\cos (\phi' - \phi) \cos AH + \sin (\phi' - \phi) \cdot \sin AH \cdot \cos AHP \ldots (6).$$

In the $\triangle$ APB:

$$\sin AB : \sin AP = \sin P : \sin ABP$$

$$\therefore \sin ABP = \sin P \cdot \frac{\sin AP}{\sin AB} = (l_1 - l) \cdot \frac{\cos \phi}{\sin AB} \ldots (7).$$

In the $\triangle$ PDB:

$$\sin PB : \sin PD = \sin \frac{\pi}{2} : \sin DBP$$

$$\therefore \sin PD = \sin PB \times \sin ABP = \cos \phi' \cdot \sin ABP \ldots\ldots (8).$$

Equation 8 gives us the "highest" latitude—the value of PD.

Then by the diagram, the construction of which has been discussed, the course can be laid down.

The Gnomonic-Projection simplifies the calculation greatly; and, at the same time, when not greatly distorted, shows the features of the Land lying in the course, which is an important consideration.

H. W. C.

No. CCLXIII.

DESCRIPTION OF MANDI SUSPENSION BRIDGE, 240 FEET SPAN.

[*Vide* Plates I., II., III., IV. and V.]

By Lieut. C. Hoskyns, R.E., *Asst. Engr., Special duty, Mandi.*

bridge, which has just been completed, was designed by F. Kirby, Esq., Exec. Engineer, M.I.C.E., and erected by Lieut. C. Hoskyns, R.E., Asst. Engineer, Special duty, Mandi.

It spans the Beas, opposite the town of Mandi and was much needed, for during the rainy season, communication with the right bank of the river was almost entirely cut off, the ferry being unable to ply. The river rises 25 feet above cold-water-level when in high flood.

The cost of this bridge has been defrayed by the Rajah of Mandi.

The site selected is an admirable one. On both sides the piers are founded on rock, and on both sides, above the bridge, large rocks jut out into the river, acting as natural breakwaters.

In working out the design one paramount object was kept in view, viz., rigidity, as far as practicable. In a Suspension bridge, unless the superstructure is so designed as to be strongly braced both vertically and horizontally, the lateral and undulating motions of the bridge would expose it to violent deranging forces in every direction. Cases have been known of suspension bridges being completely wrecked in consequence of there being no effective guards against vertical and lateral undulation.

CALCULATIONS—

Clear span, effective,	..	..	..	240	feet.
„ main cables,	..	..	..	265	„
Breadth of roadway,	..	..	..	10	„
Roadway beams,	..	..	..	3	„ apart
Versine,	..	..	..	15	„

CALCULATIONS.—(*Continued.*)

Dead load from measurement, ... 60 tons.
Live load at 80 lbs. per square foot, ... 85 ,,

Total dead and live load, ... 145 ,,

Strain at centre $\frac{CL}{8V} \cdot \frac{255 \times 145}{8 \times 15} = 308$ tons.

Strain on cable at pier, .. = 320 ,,

There are 12 cables—

∴ Strain on each cable, .. = 26·6 tons.

The cables are of steel wire, 2 inches diameter, with steel core; the cable tested up to 137 tons, (*see* Mr. Kirkaldy's experiments, which are annexed,) so that the cables are strained up to one-sixth working load.

Plates I., II., III., give detail of superstructure of the bridge.

It will be observed from *Fig.* 2, *Plate* I., that the main cables are pulled inwards towards the centre of the span. The distance from centre to centre of main cables at piers is 18 feet. At centre of the span the distance is 14 feet. As the weight of each portion of each cable between piers is one ton, we have a weight of 12 tons pulled out of its horizontal position two feet, and this force naturally tends immensely towards the rigidity of the bridge.

It will be also noticed that the horizontal bracing underneath the roadway is proportioned much as a vertical girder of a certain span would be, viz., the braces increase in area as they approach the piers.

The railings, or more correctly the vertical girders, have been given a height $= \frac{1}{2}\sqrt{\text{span}}$, and particular care was bestowed upon the strength and arrangement of joints, so that they present the maximum amount of resistance against undulations and lateral motions.

Plate III. gives the detail of main saddles and of suspending saddle.* It was originally intended to have had a cast-iron framing for pulleys in the main saddle, but I found that I could quarry stones of excellent quality and large; and, consequently, proposed to Mr. Kirby the present design, which was approved of. This arrangement was of course far

* If the saddles had been arranged as in this figure, to go over pairs only of cables, it would have been a more economical and perfect method. A plate should be placed at such intervals as considered necessary, loosely bolted to another plate under cables. These plates would prevent the main cables from laterally swaying in pairs and keep the group compact. Each pair of cables in this case would carry a saddle at every nine feet. By working in pairs in echelon the difficulty of swinging the group of cables to exactly the same dip is COMPLETELY overcome, and also the size of cables need not be ever greater than 2-inch diameter as a maximum, the STRENGTH to be gained by additional pairs, to which there appears to be no practical limit.

cheaper, and where good stone is to be found, is to be recommended in preference to cast-iron framing.

The method of fixing ends of railing, (*see Plate* III.,) allows free longitudinal play to the railing, while preventing the ends from tilting up. It is a modification of an arrangement used by the American Engineers for tying down the ends of railings, and yet allowing longitudinal play.

Description of anchorages, and method of fixing anchorage links and cables.

Fig. 2, *Plate* I., shows the plan of tunnels, and *Plate* II. shows the detail of anchorage links and box girder.

The rock is very hard blue sandstone, and the tunnelling proved a very laborious and expensive work.

The main tunnels for anchorages are 27 feet in length by $4' \times 3\frac{1}{2}'$, and driven parallel to slope pertaining to the back stays of main cables. The rock was found too hard to cut, and small blasts of about 6 inches in depth were used. The progress was on an average about $1\frac{1}{2}$ to 2 feet a week.

Tunnels $8' \times 7'$ were also driven to communicate with the box girder anchor chamber. Fortunately from the shape of the rock they were not very long.

At first it was intended to have a cast-iron anchorage plate $5' \times 3'$ through which the links would pass, and be keyed up; the idea being to cut a narrow channel of just sufficient depth to allow the links to pass through and about 7 feet in length.

The rock however was too hard to cut with the tools available, and blasts did not admit of the construction of a narrow channel. I proposed therefore to Mr. Kirby, October 1876, a box girder of dimensions given in *Plate* II., the links to pass through the flanges. This was agreed to. The girders were made at Roorkee and weighed 22 maunds each.

The links for the anchorage were of the best Lowmoor iron, and were tested by Mr. Kirkaldy of London. There are two sets of links $14' \times 6'' \times 1''$, connected by one set $4' \times 6'' \times 1''$ by steel pins $4\frac{1}{2}$ inches diameter, as shown in *Plate* II.

The fixing of anchorage links requires but little description: the box girders were first placed in position in their respective chambers; the links were then passed down the tunnel one by one; the men in the

chambers then passed the steel pin through the lower consecutive set of nine links, and the connecting links. A heavy wooden mallet was used for this work.

The remaining links were then passed down, the second pin passed through, and finally the third pin was passed through the head of the anchorage links and pulleys.

It took about three days to fix the anchorage. This was entirely owing to the confined space in the tunnels. A tunnel $3\frac{1}{2}' \times 4'$ gives but little elbow room, and a good deal of manipulating was required to get the pins to pass through the consecutive set of links.

Plate II. also shows method of fixing cables to anchorages. Details of clip are also given. This clip as first proposed had no side screws or gun-metal bush at the bottom. The experiments made by Mr. Kirkaldy showed, that with a pull of 30 tons the clips as first designed, followed the twist of the rope.

The present arrangement has completely stopped this. The bush offers more surface for friction than a flat plate, and the gun-metal wedges at A, A, *Plate* II., when screwed up tight prevent any tendency of cable to flatten, besides having an immensely strong holding power.

An account of the results of experiments made by Mr. Kirkaldy on the wire ropes show conclusively that the clip is a most reliable join, for in all cases the cable broke clear of fastenings.

The results of experiments are herewith annexed.

MANDI BRIDGE.

Results of Experiments to ascertain the Tensile Strength, and rates of Extension, of four pieces of Steel Wire Rope, manufactured by, and received from, Messrs. Wilkins and Weatherly.

Test No.	Description	Labelled	Circumference	STRANDS: No. of strands	STRANDS: No. of wires	STRANDS: Diameter of wires	Wires, total number	Main core	STRESS IN POUNDS—EXTENSION—INCH: Length, inches	20,000	40	60	80	100,000	120	140	160	180	200,000	220	240	260	280	300,000	ULTIMATE STRENGTH: lbs.	ULTIMATE STRENGTH: Tons	Remarks
L.																											
686	Steel "G.H.,"		6·49	6 1	19 19	·1366 ·1467	133	Wires	100	·07	·14	·30	·37	·47	·58	·68	·75	·98	1·21	1·42	1·68	1·92	2·47	3·09	308,590	137·76	4 Strands together, others separately clear of fastenings.
				of soft steel																							
684	Do. "C.D.,"		do.	do.	do.	do.	do.	do.	100	·07	·14	·21	·28	·37	·48	·59	·70	·85	·98	1·19	1·40	1·68	1·96	2·55	308,480	137·71	
687	Do. "I.J.,"		do.	do.	do.	do.	do.	do.	100	·07	·14	·21	·28	·37	·48	·59	·69	·90	1·07	1·31	1·59	1·82	2·45	2·94	305,360	136·32	
685	Do. "E.F.,"		do.	do.	do.	do.	do.	do.	100	·07	·12	·20	·28	·35	·48	·60	·70	·89	1·04	1·22	1·46	1·79	2·12	2·75	304,830	136·08	
								Mean,		·07	·14	·23	·30	·39	·50	·61	·71	·90	1·07	1·28	1·53	1·80	2·25	2·83	306,815	136·96	

MANDI BRIDGE.

Results of Experiments to ascertain the Tensile Strength, and rates of Extension, of one piece of Steel Wire Rope, manufactured by, and received from, Messrs. Wilkins and Weatherly.

Test No.	Description	Labelled	Circumference	Strands: No. of strands	Strands: No. of wires	Strands: Diameter of wires	Wires, total No.	Main core	Stress in pounds—Extension—inch: Length inches	20,000	40	60	80	100,000	120	140	160	180	200,000	220	240	260	280	300,000	Ultimate Strength: lbs.	Ultimate Strength: Tons	Remarks
K. 5953	Steel,	..	6·49	6	19	·1266	133	Wires	100	·07	·14	·20	·29	·39	·49	·61	·72	·89	1·01	1·20	1·43	1·68	1·99	2·63	308,370	137·66	4 Strand together, others separately clear of fastenings.
				1	19	·1467																					
				of soft steel																							

Abstract of different items of expenditure on the Mandi Suspension Bridge Works.

IRON WORKS.

	RS.
8 Steel wire cables, 2 inches diameter and 430 feet long, at Rs. 2,267 each, ...	18,136
Anchorages, consisting of 72 links, 14′ × 6″ × 1″; 72 connecting links, 4′ × ½″ × 6″; 12 steel pins, 3′ 3″ × 4½″ diameter; 8 steel keys; 24 cast-iron pulleys; and 36 washers, ...	14,842
Box girders for anchorages, at Rs. 344 each, ...	1,376
Bolts, nuts, straps, suspending saddles and stirrups, and spindles and wheels main saddles, ...	4,317
Cost of experiments on ropes and on clips by Mr. Kirkaldy, ..	1,890
Cost of clips, 160 in number, ...	1,900

MASONRY.

Purchase of country iron,..	1,180
46,254 c. ft. 1st class coursed rubble masonry, at Rs. 28 per 100, ..	12,951
5,451 c. ft. dressed cornice, &c., at Rs. 100 per 100, ...	5,451
2,665 c. ft. deodar timber in superstructure at Rs. 2-2 per foot, ..	5,740
Fixing anchorages and swinging cables, ...	505

TUNNELLING AND BLASTING.

112 running feet of tunnel, 3½′ × 3′, at Rs. 5 per foot, ...	560
12 „ „ „ 6′ × 5′, at Rs. 12 per foot, ...	144
Blasting rock, ...	700
Approaches, ...	454
Sundries, ...	500
Carriage of material from Calcutta, and from Rupar to site, ...	7,700
Carriage of iron-work from Roorkee to site, ...	1,171
Establishment for 20 months, ...	1,838
Total Rs., ...	82,851

Description of methods used in Swinging Cables and Superstructure.

After having fixed the anchorage links in position, as described above, rangements were made for hauling the main cables across the river.

Each cable weighed 1½ tons.

A ship's capstan, which was made in the timber-yard, was placed in a

suitable position on the right bank of the river. A small wire rope of 1 inch diameter was passed across, having been previously fastened to anchorage on the left bank. It was hauled taut by means of the capstan and securely fixed to anchorage on right bank. Its dip at the centre was not much more than three feet.

A good hemp rope was now passed across from right bank and made fast to one of the main wire 2-inch cable as in *Fig.* 2, *Plate* IV. Runners were collected on the pier (A). As the main cable, was hauled across by the capstan, these runners were fixed at intervals of about 20 to 30 feet. *Figs.* 2, 3, 4, 5, *Plate* IV., will show the detail of the runner. The wedge prevented the cable from slipping.

It took on an average about one hour to haul the cable across, and the remainder of the day in passing it round the pulléys in anchorage, and attaching clips.

These runners answered admirably, and eight men at the capstan were sufficient.

When the clips were screwed up and everything secure; a man on a *jhūla* on a spare wire rope was hauled across the river from pier to pier, striking out, as he passed along, the wedges from the runners. The cables then assumed a dip of about 6 feet producing a strain of 5 tons from their own weight. This sufficed to stretch them considerably. Their dip in centre increased some 7 or 8 inches. After allowing the cables to remain in *statu quo* for six days, after which their dip at centre did not increase, arrangements were made for slacking the cables down to their permanent dip, namely 17 feet at centre of span.

As there were six cables in either group some difficulty presented itself in getting them all of the same dip. The slightest movement in the length of back stay is exaggerated some five or six times at the centre of the dip. The movement of $\frac{1}{8}$-inch in back stay means a rise or fall of one in the dip. At first it appeared almost impossible to work with such nicety with such heavy loads. Until the following expedient was hit upon, which proved most satisfactory.

A good stout nail was passed through the cable end, and by this a double headed screw was made fast, as in *Fig.* 6, *Plate* IV., which explains itself.

All the clips but one were then taken off the cable, and the one remaining (*a*) being *loosened* only; the wire cable was relieved and the pull to

a certain extent transmitted to the double-headed screw, the clip still taking a good portion of the pull. By striking the cable at (*c*) with a wooden mallet, and lengthening the double-headed screw, the cable gradually settled into its place. By this method the cable was under absolute control, and the rate of slackening was regulated entirely by the screw.

When the cable was in position the clip (*a*) was firmly screwed up, the remaining clips were attached, the screw (*b*) disengaged and attached to the next cable, and so on in rotation. I was enabled by this method to get the dip of the group of six cables exactly the same.

The main cables before they were loaded, *i.e.*, at this stage were fixed at a dip of $1\frac{1}{2}$ feet *above* what was designed. From previous experience I knew that approximately they would come down that amount when they were loaded. The girders when made on the ground were also given a camber of 3 feet, for I knew that nearly half of it would be lost in the settlement of cables.

Finally, when the bridge was completed the cables had come down about 16 inches, and the camber of superstructure remained 1 foot 8 inches at the centre. This is an important point to remember in these style of bridges. Fortunately I had built a smaller bridge before, and had remarked the great settlement.

When the two groups of cables were in position, a temporary roadway 10 feet broad was boomed out towards the centre from either pier, as follows :—

The suspending saddles, with wires and stirrups complete, as in *Fig.* 7, *Plate* V., were collected at the piers of the bridge, having been placed on the main cables. The suspending wire was permanently leaded into the stirrup, and temporarily made fast to saddle by passing a nail through.

Cross beams with ends cut, as in *Fig.* 8, *Plate* V., were collected near piers. The cut as shown in this figure enabled the stirrup to swing into its place immediately. The booming out proceeded most rapidly. When the cross beam had been fixed into the two stirrups, two men, one on either group of cables, pushed the saddle down the catenary thus booming out the cross beam, over which had been previously placed two longitudinal baulks. The principal was the same as booming out in pontooning, and I was going to say as rapid, for the temporary roadway was com-

pleted in 12 hours. Considering that there were no trained workmen this was good going. *Fig.* 9, *Plate* V., gives an end view of the temporary roadway.

As the horizontal girder underneath the permanent roadway had to be placed above the temporary roadway, this latter was swung at a height of about 2 feet beneath position of horizontal girder when permanently placed. *Figs.* 10 and 11, *Plate* V., show this.

The booms of the horizontal girder were now fixed, working from the centre of span towards the two piers. This work took about four days. Two more saw the cross pieces and tie-rods in position.

The horizontal girder complete in position; the cross transoms were placed on it in their permanent position, commencing as usual at the centre. These transoms were raised above the girder booms about 1 inch by wedges.

Now commenced the work of permanently fixing the suspending wires, and relieving the temporary roadway of its supercumbent load. *Fig.* 12, *Plate* V., will explain this. Here the reader may observe that the lower boom of railing has been placed above the cross transoms and that large bolts (*b*), (*b*) have been fixed, so as to take all the weight of the horizontal girder beneath. Having proceeded thus far, the suspending wires which were attached to the cross transoms were tautened and then run in with lead with the saddles, as follows:—

Long $\frac{3}{4}$-inch bolts were passed through the holes in saddles and its plate attached to it, (see *Fig.* 13, *Plate* V.) The wire rope was then clipped with two plates screwed together (see *Fig.* 14, *Plate* V.) The nuts of the $\frac{3}{4}$-inch bolts were then screwed up, raising the plate and with it the clip and wire rope. The end of wire rope was then opened out, as in *Fig.* 15, *Plate* V. A small conical wedge placed in hole in saddle and the whole run on with lead.

When the long bolts were put through suspending saddles to tauten suspending wires, the heads were downwards, and nuts above. This was found the most convenient as the workmen then sat on the main cables screwed the wire up as taut as could be, then opened out the rope and permanently leaded the end in. After this was done the ends bolts were unscrewed, and the proper bolts for the underneath plate attached, heads downwards as in *Fig.* 15.

Before finally fixing a saddle the wire was leaded in a little lower down

than the permanent position. The saddle was then struck up the slope with a heavy wooden mallet until it was absolutely vertical, which was determined with the plumb-bob. The under plate was then screwed up tight, and the saddle permanently fixed.

The wedges which kept the cross transoms and booms of horizontal girder apart were now struck out and these booms were screwed up by means of the screws on the bolts *b*, (see *Fig.* 12, *Plate* V.) The object of the wedges may not at first sight be understood. It was found that the cross-section of horizontal girder was not perfectly level. By means of these wedges the cross transoms were levelled, and the horizontal girder was afterwards screwed up to its proper position. When the temporary roadway had been relieved of its superincumbent weight, its suspending wires were loosened, by striking out the nail above saddle, and the pieces fell into the river; men being in readiness on '*deraves*' to drag the timber to the banks.

I need not observe that all the superstructure was framed and fitted (exactly as it would be on the bridge) on the ground, and that therefore the fixing of railing and flooring was merely fitting, and requires no description.

The first cable was swung on the 21st August; the temporary roadway thrown across on the 22nd September; the horizontal girder fixed in position six days after that; and the bridge completed on the 14th November.

Notes on Carriage of Steel Cables and Ironwork for the Mandi Suspension Bridge, viâ Rupar, Kalakhand, Belaspur, Suket, Mandi. Distant 65 miles.

The material for the Mandi Suspension Bridge arrived at Rupar during the first week in June.

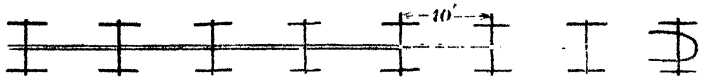
It consisted of 12 steel wire cables 2 inches in diameter each 430 feet long and weighing 42 maunds, of 72 wrought-iron links 14′ × 6″ × 1″, weighing each 4½ maunds, and of other smaller pieces.

The total weight to be carried from Rupar to Mandi, distant some 65 miles over bad hill roads, was

12 cables, ...	504	mds.
Wrought-iron work, ...	500	,,
Total, ...	1,004	,,

Speaking roundly, loads for 2,000 men.

The method of the carriage of ironwork needs no comment, that of the cables however presented some difficulties. The cables having been placed on an improvised drum previous to uncoiling, were unwound to their full length. They at first rebounded much like a watch spring, after being kept taut for some little time the cable was doubled on itself and bamboos were fastened at every 10 feet,



thus providing for 84 men, each man having a load of 20 seers. The total length of load as carried was 215 feet.

From Rupar to the foot of the hills, distant some 18 miles, the men experienced no difficulty with their load, and accomplished the distance in two days.

From the foot of the hills to the top of the pass, distant some 6 miles, the cables were on an average carried in one day. The ascent, though in some places sharp is fairly straight, and presented no difficulties in the carriage.

From the top of the pass on to Belaspur the road is very bad and tortuous. The zig-zags are very sharp, and here considerable difficulty was experienced. It was found necessary to place men at each angle of the zig-zag to help the men round with their load. On an average three days were taken between Kalakhand and Belaspur, distant about 16 miles.

There was not the slightest tendency for the cables to kink. In fact carried as they were it was perfectly impossible for them to do so. To kink, a cable must turn over on itself, and with men at every 10 feet, however sharp the zig-zag, this could not possibly happen.

From Belaspur to Mandi, the road is fairly level and good, and the rate of progress was on an average somewhat under two days per stage of 10 miles. No difficulty was experienced in crossing the Sutlej at the Dehūr ferry.

The total time taken for carriage of material to Mandi was two months. This of course does not represent actual going. Much time was necessarily expended in collecting coolies. Two thousand men are not massed in a day, and without the active assistance received from the

Rajah's of Nalagarh, Belaspur, Suket, and Mandi, I should have failed in commanding labour.

The cost of carriage of 1,004 maunds from Rupar to Mandi was Rs. 4,200, coolies receiving 4 annas per stage.

The chief difficulty in the transport of a load like a long cable, lies in the management of the men themselves. Two or three men who choose to obstruct, can do so most effectually, entirely stopping progress, and this is exactly what happened.

The difficulty was in a great measure overcome, however, by having a few spare men at hand who replaced the obstructives, these latter securing nothing for any work they may have done.

This they did not like for they found that sulking did not pay.

Notes on Carriage of Steel Cables and Ironwork for the Kulu Suspension Bridge 300 *feet span*, viâ *Rupar*, *Kalakhand*, *Belaspur*, *Mandi*.

The main cables for the Kulu bridge arrived at Rupar in May.

Each cable is 500 feet in length and 72 maunds in weight. An attempt was made to carry these cables intact. One was so carried for nearly 40 miles, and another about 18 miles, but the cost proved prohibitive, as will be shown hereafter.

The cable was at first stretched out to its full length, and judging by the weight 140 men were at first provided for by fastening bamboos at regular intervals. These however could make no way, the cable got a swing on, and the men with difficulty kept their feet. Finally 240 men carried the cable off, and along the level road to the foot of the hills progressed at the rate of five miles a day.

From Kalakhand to Belaspur the road ascends some 4,000 feet to descend again, the distance is some 16 miles. Here great difficulty was experienced, the progress being perhaps at the rate of two miles a day.

At each turn of the road, as in the case of the Mandi cable, men were placed to help round the cable and finally Belaspur was reached, a week having been spent in the 16 miles between Kalakhand and Belaspur.

From the above results it was evident that the cost of carriage of cable intact was prohibitive, and arrangements are in hand for cutting the cable and joining.

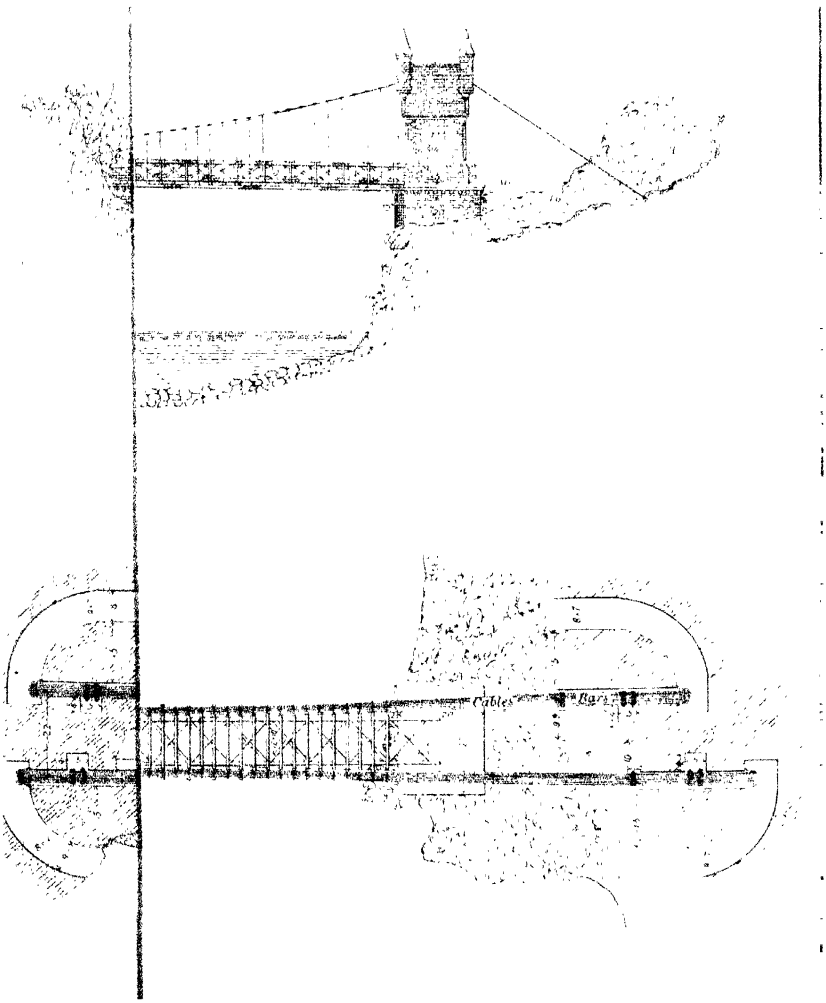
The experience gained shows that wire cables up to 2 inches diameter, and from 4 to 5 hundred feet in length, can be carried, without much difficulty at a fair rate of progress, over bad and tortuous hill roads.

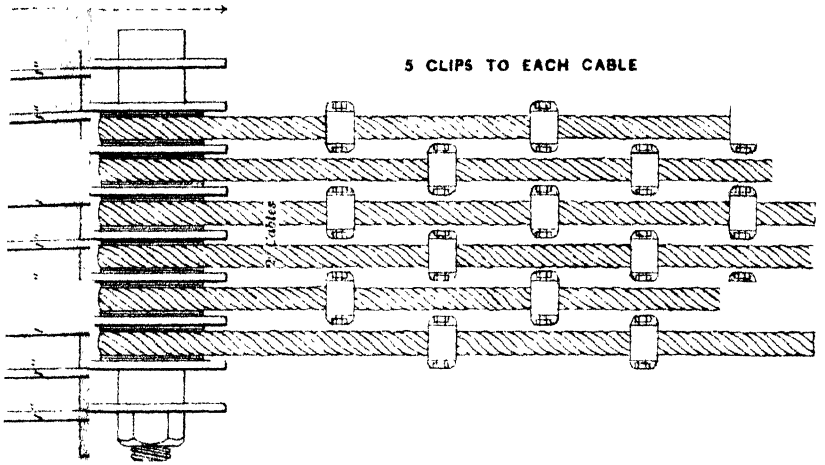
The progress in the case of the Mandi 2-inch cables was good considering everything. Each man carried an average load, and no advantage would have accrued in cutting and carrying smaller bulks of cable.

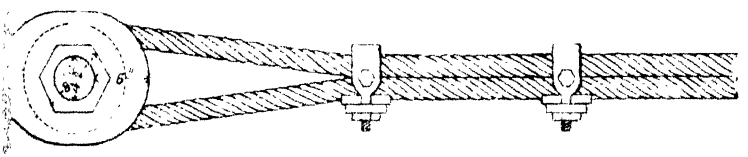
And it appears that it does not pay to carry wire cables of a greater thickness than 2 inches diameter. The carriage of the Kulu cable, 3-inch diameter, 500 feet long and 72 maunds in weight, over some 40 miles of bad hill road, shows that a cable of great weight and thickness *can* be carried, but that it does *not pay* to do so. The number of men required for the 3-inch cable increased inversely as the rate of progress.

In designs for suspension bridges in the hills, wire cables of greater thickness than 2 inches diameter should not be used. The required strength must be supplied by numbers NOT by increasing the thickness of cable.

C. H.

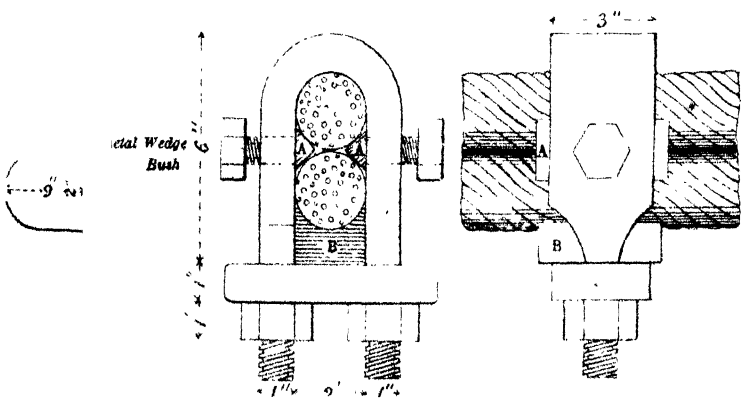

Cables
Bars





ENLARGED VIEW OF CLIP

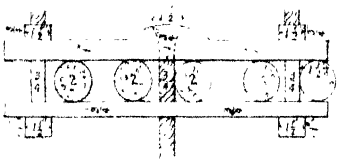
Scale. ½ real size.



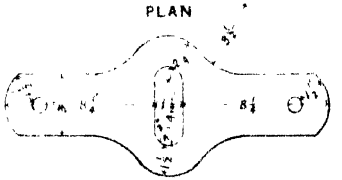
DETAIL $\frac{1}{16}$.

SADDLE FOR SUSPENDING WIRES

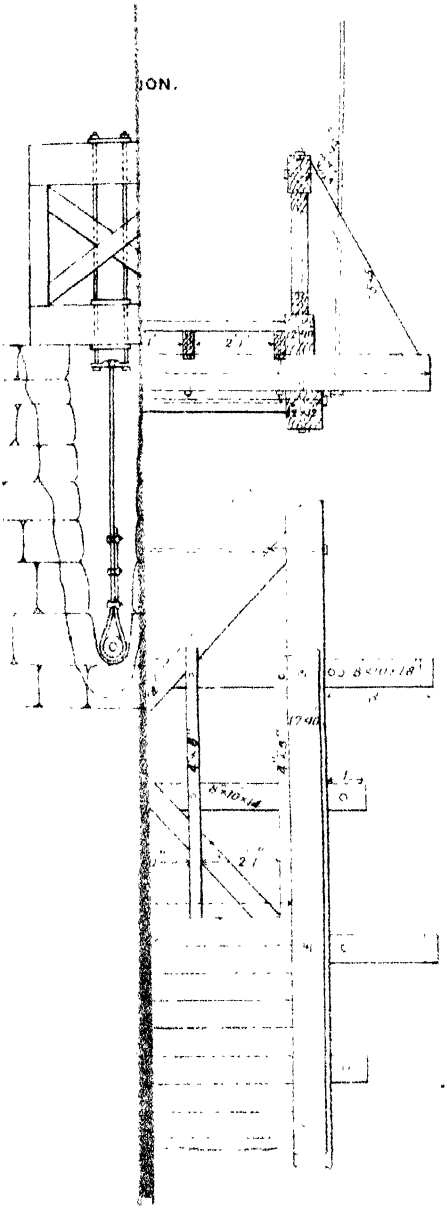
Elevation



PLAN



ION.



STIRRUP

Elevation



PLAN



FIG. 13.

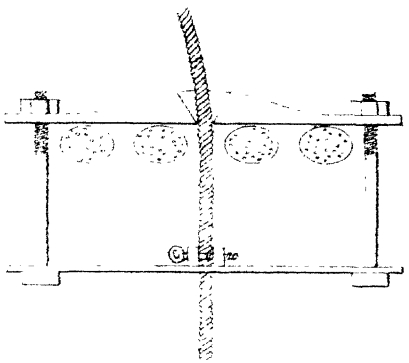


FIG. 14.

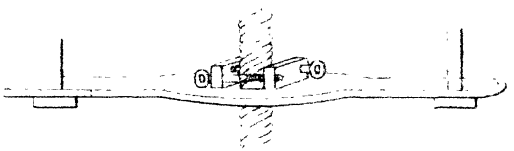
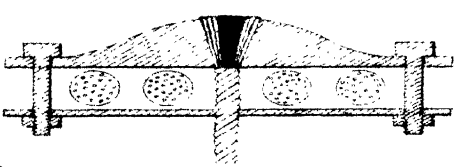


FIG. 15.

SECTION



Lower Boom of Railing

Horizontal Girder

railway

PLAN



No. CCLXIV.

NOTE ON COAL IN THE SEWALIK HILLS.

By Murray Thomson, M.D., F.R.S.E.

It has been known for many years that small deposits of coal, or rather lignite, occur here and there among the sandstones of the Sewalik Hills. If this mineral can be obtained in sufficient quantity to repay the working and carriage of it, it will be valuable as a fuel, whether its nature be that of a true coal or a lignite.

I have lately examined some samples of this lignite at the request of the Secretary to the Government, N. W. Provinces, in the Department of Public Works, and as I have not met with any published statement of the composition of the mineral, it might be as well to put on record the results of my experiments on the samples sent to me.

The samples which I examined were found by Mr. Marten of the Forest Survey Department. The following Table gives the sites from which they were taken, along with their composition per cent.:—

Place or site from which the sample was derived.	Fixed carbon.	Volatile matter.	Ash.
1. Sahensa Rao, ...	39·69	39·73	20·58
2. Halni branch of Sahensa Rao, ...	53·78	16·05	30·17
3. Chumari Sont branch of Sahensa Rao, ..	45·12	39·05	15·83
4. Kotri Rao, ...	38·98	42·70	18·32
5. Sháhjahánpur Rao, ...	48·28	47·62	4·10

All the samples, except No. 2, compare well with Indian Coals gene-

rally, and No. 5 might be considered excellent fuel, on account of its freedom from ash. However, regarding the suitability of these lignites for fuel, the composition of them is somewhat misleading. The volatile matter, which exists in common coal as bitumen, is different in these lignites: they never cake during combustion, and the amount of inflammable gas they give out is very small. This prevents them burning readily, and for complete combustion they require a strong draught. This difficulty of burning is also caused by the want of coherence of the lignite. They crumble to pieces very easily: this would lead to great waste in extracting the lignite from its bed, as also in carrying and using it. The results of my experiments do not foster high hopes as to the usefulness of these lignites as a fuel.

I know nothing myself as to the thickness or extent of the beds but they have been well examined by a very competent authority, Mr. H. B. Medlicott, who remarks on them: "I have seen a great deal of these rocks, and I think that the prospect of a useful deposit of coal being found in them is very unpromising. The nests and strings of lignite that occur, sometimes close together, in the sandstones are manifestly the remains of isolated trunks and roots of trees which were rolled or floated into these positions and became buried in the sand. There is, of course, the chance of a local accumulation of such matter, but this has not been the mode of origin of useful coal seams."*

M. T.

* Memoirs of the Geological Survey of India, Vol. III., Part 2, page 180. Geological Structure, &c., of Southern Himalayas, by H. B. Medlicott, B.A., F.G.S., now Director of the Geological Survey of India.

No. CCLXV.

FESTINIOG LIGHT RAILWAY.

Copy of a letter from GUILFORD L. MOLESWORTH, ESQ., *Director of Public Works, Ceylon, to the Right Hon'ble the Secy. of State for the Colonies.*

London, March 24th, 1871.

MY LORD,—In accordance with the suggestions of Sir James Elphinstone, I have visited the Festiniog Railway, and have now the honour of laying before you my views respecting it.

I have already reported at some length to the Government of Ceylon on the subject of light railways; and, as my visit to Festiniog has not materially altered the opinions I then expressed, my Report will, to a great extent, consist of a repetition of those views.

The Festiniog line was originally opened as a horse tramway or railway for the purpose of connecting a large group of slate quarries with Portmadoc, the nearest harbour. The length of the line is about 13¼ miles, with a branch of a mile in length making a total of about 14¼ miles; it passes through a rough country, but the curves enable it in most parts to keep tolerably close to the contour of the hills, and to avoid heavy works, except here and there; there are however two tunnels unlined of 60 and 700 yards respectively, and some heavy rock cuttings and embankments. The terminus of the main line is about 800 feet above the level of the sea; the average gradient is about 1 in 90, and the maximum gradient (with the exception of a short and unimportant portion at the top) is about 1 in 80; practically, the line may be said to consist of one continuous descending gradient of 1 in 90 for 12¾ miles, with about a mile of level at the end nearest to the shipping port. The traffic on the railway is about 140,000 tons annually, of which about 90 per cent. is

slate, the rest almost entirely of coal and lime. There is also a passenger traffic of about 90,000 or 100,000 passengers per annum, chiefly composed of workmen or others connected with the slate quarries.

The line was for thirty years worked by horses, which drew the empty trucks up the gradient, and were themselves in their turn brought down with the loaded train in trucks specially constructed to carry them, as the gradient is sufficient to enable the loaded trains to descend by their own weight without any motive power.

About the year 1863 the use of horses was abandoned, and a sum of £50,000 was expended out of the revenue of the railway in improving it and rendering it suitable for locomotives.

The total cost of the line is said to have been about £87,000, including the cost of rolling stock, or about £6,000 per mile.

The land through which the line passes is comparatively valueless, and the railway has been free from the ruinous expenses of a parliamentary opposition which have added so much to the burden of the majority of English lines.

The railway is a single line with a gauge of 2 feet,* and with crossing sidings about 16 or 18 chains long at intervals.

The sharpest curves are 1¾ chains, or 115 feet radius.

The formation width is 8 feet in cutting and 10 feet in embankment. The fencing is chiefly of dry stone walling, for which the natural cleavage of the rock (in laminated strata with fine beds) offers great facilities.

The culverts and smaller works are also of dry masonry, but the masonry of the bridges and larger works is set in mortar. The natural cleavage being favourable for the construction of cheap masonry, and indeed in many cases walling has been adopted for the retention of the embankments, in preference to the adoption of slopes.

The permanent way is formed of double-headed rails, weighing 48 lbs.† to the yard, fished and laid with cast-iron chairs on transverse sleepers, 9 inches by 4½ inches, and 4 feet 6 inches long. The distance of the sleepers is 3 feet apart, but less at the joints.

The rolling stock is of very simple character. The buffers are central, and about 1 foot 8 inches above the level of the rails. The coupling is also central; the wheels are 1 foot 6 inches diameter, with journals about

* 1 foot 11½ inches actually.

† I believe these have since been replaced by rails weighing about 60 lbs. per yard.—G. L. M.

4 inches long, working in white metal bearings. The wheels are of cast-iron, with wrought-iron tires, and there are also some wrought-iron wheels; but these are faulty in design.

The trucks weigh about 1 ton each, the greater number being designed with open-barred sides for slates; they have a wheel base of about 3 feet, and a capacity of about 45 cubic feet; they have no springs, and the brackets carrying the bearings for the journals are of cast-iron, bolted on to the frames.

The carriages are built by Messrs. Brown, Marshall, and Co., and are well and substantially made; they have a wheel base of about 5 feet 6 inches, and are furnished with central spring buffers, springs, and axle-boxes, working in axle guards in the usual manner. The passengers sit back to back, with their sides in the direction of the line; and the flooring of the carriages overhanging the wheels is within a few inches of the level of the rails.

The internal dimensions of the carriages are about 10 feet long by 6 feet 3 inches wide; they weigh about $1\frac{1}{2}$ tons, and are intended to carry twelve first class, or fourteen second and third class passengers, giving a width of 1 foot 8 inches for first class, and 1 foot 5 inches for second and third class, passengers.

There are two classes of engines employed for working the line—

Single locomotives, with 4 coupled wheels of 2 feet diameter, $8\frac{1}{4}$-inch cylinders, 12-inch stroke, 5 feet wheel base, and about 10 tons weight.

A double bogie engine on Mr. Fairlie's principle, with four cylinders, each $8\frac{3}{16}$ inches diameter, and two sets of 4-inch coupled wheels, 2 feet 4 inches diameter; stroke, 13 inches; wheel base of each bogie, 5 feet; total wheel base, 19 feet; pressure of steam, 160 lbs. per square inch; total weight of engine, $19\frac{1}{2}$ tons.

The latter was not working when I visited the railway. The single engines are capable of taking a load of about forty-five empty trucks, with break van, and three or four passenger carriages (or a total load of from 50 to 60 tons up the line). There are no stations to speak of, and no platforms are required for the carriages, the wayside stations consisting merely of a crossing, siding, and a hut, to serve as booking-office and waiting-room.

The slates are loaded at the quarries and unloaded at the port by agents of the respective quarries, and not by the Company's servants.

The description above given comprises the leading features and details of this interesting little railway, which reflects great credit upon all concerned in it, and shows what it is possible to do on so narrow a guage. The plan of central buffing and coupling is one that has long been considered a desideratum with engineers, but there has been a difficulty in introducing it on English railways without confusion and considerable expense. I consider it a great improvement on the system of double buffers, especially on a railway abounding in curves.

An attempt has been made, by the publication of a series of plausible letters in the "Times," about the beginning of last year, to give to lines of this character an undue importance. These letters, though useful in calling attention to the subject, have exercised a somewhat mischievous influence by giving a fictitious colour to facts which need no such misrepresentations to commend themselves; and, as this influence has been widespread, it becomes necessary that the true facts of the case should be known.

The advantages thus claimed for the Festiniog Railway may be briefly summed up as follows:—

Its working expenses are only 44½ per cent of its receipts, whereas in English lines of ordinary gauge they average 48 per cent.

It yields an interest of 29½ per cent. on the original capital, whereas ordinary lines yield only from 6 per cent. to *nil.*

The dead load on the Festiniog Railway is only one-third of the weight carried, whilst on the ordinary gauge the dead weight for similar freights is more than half the weight of freight.

On the English lines of ordinary gauge the dead load carried for each passenger is a ton, or even more, whilst on the Festiniog system it may be reduced to 5 cwt.

The exceptionally narrow gauge effects a very large saving in first construction.

The loads being comparatively light, there is an immense saving in wear and tear.

These conclusions, though apparently based on statistics, were so much at variance with the results of my own experience, that before I could adopt them, I deemed it necessary to analyze the facts carefully, to ascertain whether there were any exceptional circumstances connected with the Festiniog Railway, or whether the advantages above claimed were

wholly and solely due to the adoption of the 2-foot gauge. The first point which struck my attention was the fact that, notwithstanding the advantages claimed for the system, the expenditure per train mile was nearly double that of the average of English railways, and more than three times as much as that of some of the Irish railways, on which the rates of labour would probably more nearly resemble those of a remote Welsh district like Festiniog. The features that appear to be chiefly exceptional on the Festiniog Railway are—

That the traffic almost exclusively consists of slates; that the rate charged for freight is at least double the rates of ordinary railways;

That the traffic is almost entirely down hill, on easy gradients requiring power for little more than the haulage of the empty trucks back again, and that this circumstance has enabled the traffic to be worked with remunerative result by horses alone.

Now let us see now how these facts affect a comparison with English trains of the ordinary gauge.

I will take the advantages claimed for the Festiniog Railway *seriatim* in the order in which I have given them above.

1. The working expenses are stated to be 44½ per cent. of the receipts, but on examination of the Financial Statement for the year ended June 1869, I find that the receipts amounted to £23,696, whilst the actual expenditure has been £13,053, so that the actual expenditure has amounted to 55 per cent. of the receipts, certain deductions having been made from the actual expenditure before instituting the comparison with other railways.

Now I suppose that no deduction of this kind has been made from any of the English railways with which it has been compared, though, of course, the expenditure of all railways will be subject to charges of a character which might be excluded from "working expenses" in the strict sense of the term.

How far such deductions are fair it is impossible for me to say, but I certainly observe in the statement items which, in my opinion, cannot fairly be deducted from working expenses; for instance, tonnage for right of way, which would in ordinary railway accounts be debited to rent, and form a portion of the working expenses. Again, "rebate" (or remission of a part of the receipts to the freighter) which if deducted from the working expenses should in all fairness be also deducted from the receipts in forming a comparison between the receipts and expenses.

Waving, however, these objections, and assuming for the sake of argument that 44⅛ per cent. is the fair proportion, let us enter into a fair comparison between this and 48 per cent. of the English railways (on some of the Irish railways it is 39 and 33 per cent., and in one case as low as 31 per cent.)

The Festiniog Railway being a small line to a number of slate quarries has practically a monopoly of the traffic, consequently it can charge for transport rates higher than those charged by the majority of English lines which are in keen competition with each other. The charge for slate is 2¼*d.* per ton per mile, and 2¾*d.* for other traffic, which may be said to be almost entirely mineral, being of coal and lime. Now the mineral rates charged on the ordinary English lines vary from ¾*d.* to 1*d.* per ton per mile, or less than half the rates charged on the Festiniog Railway (in one case within my knowledge the rate for minerals scarcely exceeds one-fourth of the Festiniog rate, and that subject to rebate). It is true that, on the average of English lines, the distance is greater than on the Festiniog line, and that the terminal expenses or cost of loading would not be spread over so many miles, but on the other hand, neither the loading nor the unloading of slates on the Festiniog Railway is undertaken by the Company's servants, but by the agents of the different quarry owners, who are the freighters, so that there are no terminal expenses to speak of.

For simplifying the question, however, I will assume that the rates of freight are double those ordinarily charged, though three times would be probably nearer the mark.

Now, it is clear that whatever may be charged to the freighters, the amount of that rate can exercise no influence on the working expenses, which must remain the same whether the rate charged be 2½*d.*, or 6*d.*, or 1*d.*, or ¾*d.*

Suppose then, for the sake of fair comparison, that we take the same rates as those of other railways, which I assume to be half those of the Festiniog Railway, the receipts will be reduced to one-half, whilst the working expenses remain the same; so that the proportion of working expenses immediately amounts up to 89 per cent. of the receipts; or if we take the total expenditure, we have a proportion of 110 per cent. or an expenditure exceeding the receipts.

2. To deal with the fact that the Festiniog Line yields 29½ per cent.

interest on its original capital, I will not stop to inquire how far the average of English lines have suffered by taking up, leasing, or guaranteeing unremunerative lines to prevent them from falling into the hands of a rival Company, although this is notoriously the principal cause of low interest on the English railways. I will simply accept the facts as they stand, and form the comparison on that basis. It appears, then, that the Festiniog Railway Company, whilst working the line with horses, realized such profits, that they were enabled to expend a sum of £50,000 out of their profits, in additions to the line, and in rendering it capable of being worked by locomotive power; if this additional capital be taken into consideration, the amount of interest will be reduced to 12½ per cent. on the outlay; still this is a handsome return, but if we are to institute a fair comparison with other railways, we must see how this interest is obtained. To do so, I must again revert to the rates.

Suppose, for instance, that the Festiniog Railway Company were forced by competition or otherwise, to carry their traffic at the same rates as those adopted on other lines, which I have assumed at half the rates now charged on the Festiniog line, the receipts would at once be reduced to one-half, or instead of £23,676, they would only amount to £11,838, whilst the working expenses still remaining unaltered, would be £13,050, or a deficit, instead of 12½ per cent. interest. In these comparisons I have assumed the whole of the traffic to be a "mineral" traffic, consisting of slates, though, strictly speaking, this is not the case, but the passenger carriages only form one-twentieth of the number of vehicles; and even the other trucks which almost exclusively carry a "mineral" traffic of coal and lime, do not form one-twentieth portion of the whole. I have, therefore, simply confined my remarks to the question of slate (or "mineral") traffic, though probably some slight reduction might be made in my figures for the small amount of traffic that may not be carried at such high rates. My aim has been to place before you, in as clear and concise a manner as possible, the principles upon which a fair comparison can only be made.

The Festiniog Railway was, it appears, a profitable concern when worked by horses; and it would have been easy to establish the superiority of horse-power over locomotive power, were interest on capital, or proportion of working expenses to receipts, to be the only criterion of their relative merits.

3. I now come to the question of the proportion of dead weight of rolling-stock to freights; and in this respect the Festiniog Railway has an undoubted advantage so far as slate traffic is concerned, for slate is a heavy and compact article of freight, and a considerable weight of it may be packed in a small compass; consequently, if a small truck be sufficient to contain as much as a pair of axles can bear, the small truck must have the advantage so far as dead weight is concerned; but few of the English railways have a traffic of one uniform dense character like that of the Festiniog Railway; and it is generally necessary, in order to avoid multiplication of rolling-stock, to have a few types of truck capable of carrying freight of all kinds; but even if a railway of the ordinary gauge were to have a traffic of slates alone, I doubt whether the trucks could constructed so as to have so small a proportion of dead weight as on the 2-foot gauge.

The case, however, wears a very different aspect when we arrive at the consideration of a bulky and less weighty freight; take for example coffee in "parchment," which I suppose forms from 90 to 95 per cent. of the freight from Kandy to Colombo. Its bulk, weight for weight, must be at least eight or nine times that of slate (and this is no extreme case; for un-pressed hay, straw, and other agricultural produce, are thirty times the bulk of slate). It would be necessary, therefore, to employ eight or nine of the slate trucks to carry an amount of coffee equalling the weight of slate that might be carried in one truck; in other words, the dead load will have to be increased eight or nine fold when you begin to carry coffee in the Festiniog truck (or 34 in the case of hay and straw). This is on the assumption that the slate trucks are used for the conveyance of coffee; and I have assumed this in order to simplify the question, and show the principle involved; at the same time trucks might be designed on the 2-foot gauge, in which the dead load might be reduced below the proportions I have given in the simple comparison of bulk with bulk. There is no doubt, however, that whilst small vehicles give the least dead load for dense compact freights, the larger are more economical for light bulky freight; and this principle is evidently being recognized in those parts of India in which cotton traffic is large; for I learn that on some of the Indian railways an endeavour is being made to economize the dead load by increasing the size and capacity of the trucks.

The fourth point would be too absurd to combat, were it not so gravely

and plausibly insisted upon by the writer of the letters of the "Times," who after going into some elaborate proofs to show that a ton of dead weight or more is carried for every passenger, continues, "surely it must be a severe reproach to mechanical science so long as a ton of passengers means, according to one calculation, 20 tons, or, according to another, 33 tons, &c.," and then he proceeds to show that, by the system he advocates, carriages may be constructed so that a passenger and his dead load, instead of weighing a ton or more, may only weigh 5 cwt. Now, any one who has the slightest acquaintance with the working of railways knows that the principal causes of this excessive weight have nothing to do with "construction" or "mechanical science," but with the traffic arrangements and with the travelling public. The dead weight is caused by the necessity for providing for the maximum number of passengers that may possibly travel on the railway, by the haulage of empty carriages, by the system practised by the travelling public of reserving empty compartments for themselves, and innumerable facts well understood by traffic managers. Even the most superficial observer travelling on the English railways must have noticed, especially on branch lines, that the carriages are seldom filled to a third of their capacity, and that many are quite empty. This explains the secret of the immense dead weight. Whilst travelling on the Festiniog railway I noticed that, so far as the first class traffic was concerned, the dead load exceeded $2\frac{1}{2}$ tons per passenger without taking into account the share of dead load of engine and break-van, for there was only one passenger in the carriage on the up journey and none on the down. Our third class carriages on the Ceylon railway, when they are properly filled (as they almost always are) do not amount to 4 cwt. per passenger including the weight of the passenger—and they are of no special construction—so that the wonderful improvement of 5 cwt. expected by the writer in the "Times" is by no means so great as it appears to be on paper. There is certainly room for the reduction of dead load in the construction of carriages to a limited extent, but the travelling public of England will not bear it. I remember that, several years ago, on a railway in the north of England, some carriages were constructed which reduced the dead load to $1\frac{3}{4}$ cwt. exclusive of the weight of the passenger himself, but it was found that, practically, these carriages involved more dead weight than those of ordinary construction because the public objected to travel in them and the

passengers in them were but few. After about a year's trial they where withdrawn. As a rule, the dead weight due to faulty construction or wasted space (both in goods and passenger traffic) is a mere bagatelle compared with that necessitated by traffic arrangements.

I now come to the cheap construction of light railways. This advantage on investigation will be found to be less than might at first sight be imagined. The cost of land will be nearly the same in the case of the light railway as it is in that of the broader gauge.

The fencing, the telegraph, the signals—precisely the same.

The stations: nearly the same, the sidings longer, because a decrease in the width must entail increase in the length of the trains.

The permanent-way will, perhaps, show the greatest saving, but that will be effected chiefly in the sleepers; it is a significant fact that the rails adopted on the Festiniog Railway are of greater weight than those originally adopted and used for many years on the 7-foot gauge of the Great Western Railway; on the other hand the Great Western rails were laid on longitudinal sleepers which admit of some reduction in the weight of rails.

The saving in the earth-work varies very much, but decreases relatively with the magnitude of the work; take as an extreme instance, the heavy embankments required to keep the Gampola Railway above flood-level; in an embankment of 50 feet height, with slopes of $1\frac{1}{2}$ to 1, the slopes which form the principal portion of the contents will remain the same, whatever may be the gauge, the only saving is a slip cut from the midde of the embankment, and each foot saved in width would only represent a total saving of $\frac{1}{80}$th part of the whole, in other words, a little more than 1 per cent. The saving in bridges of large span would be but small because the weight of the train bears so small a proportion to the weight of the bridge itself. The culverts cannot be reduced to any appreciable extent except slightly in length—the faces would remain the same. The difference of cost between a 7-foot gauge and the ordinary $4 \times 8\frac{1}{2}$ gauge, is considered by engineers who have investigated the question, to be about 7 or 8 per cent. Even Captain Tyler, R.E., who has so strongly advocated the light system, and whose position as Government Inspector of Railways has done so much to bring the subject prominently before the public, even he admits that, "in flat countries very little saving can be effected by reducing the gauge:" but he believes that, "in mountainous districts,

sharper curves which work more easily in the narrow gauge can be better employed so as to enable costly works to be avoided." If this be the case, then comes the question:—"Are sharp curves precluded by the ordinary gauge?" A few years ago such a question would have been answered in the affirmative, for when the Ceylon Railway was first designed it was almost unique amongst railways, and I had no small opposition to overcome in the Colony, because the curves in my proposed line were so sharp. My proposal was then designated as "a series of zig-zags and chamois-leaps at right angles to one another."

Since that time however, the extension of railways to districts previously considered inaccessible to the locomotive has led to the adoption of still sharper curves; and the attention of engineers has been directed to the improvement of rolling stock so as to enable it to pass without difficulty round such curves. The sharpest curves of the Festiniog Railway are 115 feet radius, and the wheel base only 5 or 6 feet; but lately a steam carriage, 43 feet long, has been exhibited near London running round curves of only 50 feet radius at a speed of 25 miles per hour on the ordinary gauge of 4 feet 8½ inches, so that the greatest element of economy claimed for the exceptionally narrow gauge, is, to some extent, illusive, inasmuch as with the ordinary gauge curves can be used which are twice as sharp as the sharpest curves on the Festiniog Railway.

It now only remains for me to discuss the sixth advantage claimed for the Festiniog system, being that the light character of the rolling-stock reduces the wear and tear considerably. This is true to a certain extent, but less than might at first sight be imagined, because it must be remembered that the great causes of wear and tear on English railways are the high speed and heavy engines; in fact, this is admitted in the letters of the "Times," from which the following is a quotation:—"The carriages and waggons are comparatively innocent. Go to him" (the engineer of the line) "and he will tell you—'We carry millions of tons on our line, and we ought to carry as many millions more without hurt, were it not for So-and-So's engines; they tumble and grind along and break down all before them. What should be a perfect road for years, with not more than two men per mile to look after, is now hammered out, in as many months, with five times the number of men to look after.'"

Now, heavy trains combined with high speed require heavy engines, and cannot be adopted without extensive wear and tear; but the Man-

chester and Liverpool Railway was for many years worked by locomotives as light as those used on the Festiniog Railway, and I well remember the time when the southern division of the London and North Western Railway between London and Birmingham was worked by small four-wheeled engines, scarcely one-third the weight of the present monster engines.

There is no reason why light engines, and even wagons and carriages of a lighter character, should not be employed on railways of ordinary gauge, provided the speed be restricted.

To recapitulate. I am of opinion that the advantages claimed for the Festiniog line may be disposed of as follows:—

The proportion of working expenses to receipts would be far greater than that of the average of English lines, were the rates of freight the same.

The interest of 29½ per cent. would dwindle down to a deficit, were the ordinary mineral rate charged.

The advantages of dead load do not hold good in the case of lighter and more bulky freights than slate.

The dead load of passenger traffic is due to traffic arrangements rather than to any specialty of construction.

The sharp curves which are claimed as the principal cause of saving in construction are not peculiar to the Festiniog gauge.

Light engines and rolling stock may be employed without having recourse to the exceptionally narrow gauge.

There are few lines England in which the traffic descends by its own gravity, as on the Festiniog Railway, or on which the greater part of the traffic requires no power beyond the hauling back of the empty trucks; the gradients are most favourable, being practically about 1 in 90 for the whole distance, and yet the expenses per train mile are nearly double those of the average of English lines, and three times those of some of the Irish lines.

An endeavour has been made to show that the working expenses should be greater on the Festiniog line, because the trucks are hauled back empty; but on the other hand it must be remembered that the traffic is of such a character that the trucks one way may be filled to their full extent, and that as the traffic is "through" there is but little shunting, so that at least half the capacity of the trains may be considered to be utilized; whilst on ordinary railways, as a general rule, taking into ac-

count miscellaneous freights, half loads, and empty returns, scarcely more than one-third of the trains run can be considered available.

Moreover, the comparison has been made between the working expenses of a low speed railway, and those of high speed railways. Now high speeds must be proportionally more expensive than low, the tractive force of 12 miles to that of 50 miles being about as 1 to $2\frac{1}{2}$, apart from any consideration of increased wear and tear from impact.

In bringing forward arguments to refute the extravagant claims set up for the exceptionally narrow gauge, I do not wish to condemn either the light system or the Festiniog Railway. I believe that the former possesses many advantages, and may be adopted with great advantage under suitable circumstances; and the latter is a most interesting work, and reflects great credit on the engineer for the manner in which he has overcome the difficulties of working so small a gauge, and for the successful introduction of locomotives on it; but I do protest against the conclusion, that the facts elicited by the working of the Festiniog Railway prove its superiority over the ordinary gauge under all circumstances, as its supporters endeavour to show.

It is not unusual when engineers bring forward arguments in opposition to the light system to consider that their opposition is actuated by "antiquated notions;" that they are attached to the orthodox plans to which they have been accustomed all their lives, and that, consequently, they are averse to any change.

I believe, however, that my antecedents will free me from any such imputation, and my past reports to the Government of Ceylon show that I have for years contemplated the introduction of light railways into Ceylon, should it be determined to open up certain mountain districts by railway communication; it would, however, be, in my opinion, a great mistake to make a break of gauge in carrying out the extension to Gampola; the features of the country are such that little, if any, saving would be effected by the adoption of a different gauge from that of the main line, and as Gampola is a centre into which the traffic of several districts converge, it would be most unwise to have a break of gauge between it and the main line; for in that event it would be more advantageous to the freighters to cart their traffic a few miles further along the road to the main line rather than despatch them at Gampola to be subject to a change of vehicle after a few miles of railway journey.

The evils of a break of gauge are not to be overlooked, and the advantages should be well marked to justify it. I feel sure that, if the Gampola Extension were to be laid to any other gauge than that of the main line it would, at some future time, be relaid to the proper gauge. The Arconum and Conjeveran Railway, not many years ago, was laid down on a 4-foot gauge and was intended to inaugurate a new system of light railways for India. There was no necessity in that case for any departure from the regular gauge, and I learn that it is now being relaid to the regular Indian gauge of* 5-6, after a heavy sacrifice of rolling stock and permanent way. I am strongly of opinion that reform in rolling stock is much more required than in gauge, and I think it would be well when any gauge has been once adopted in a country, to see how far it may be possible, by means of modern appliances for passing round curves, by engines specially designed for low speeds and by light rolling stock, to secure the advantages of a light railway, without having recourse to a break of gauge.

[The above is rather old having been written in 1871, but may be interesting as dealing with some of the fallacies which have been put forward by the extreme partisans of the Narrow Gauge.]

G. L. M.

January, 1878.

* This alteration was to have been carried out as a part of the Carnatic Railway System, but the Carnatic Railway having been amalgamated with the Great Southern of India Railway, it has been decided to alter it to the metre gauge which has been adopted on the amalgamated lines. —G. L. M.

No. CCLXVI.

CONSTRUCTIVE DETAILS OF RACK-RAIL RAILWAYS, AND OF THEIR ROLLING STOCK.

[Vide *Plates* I.—XII.]

[From the German.]

Translated and Condensed by Major J. L. L. Morant, R.E., *District Engineer, Nilgiris.*

28th January, 1878.

It is here proposed to give further particulars of this interesting system of Mountain Railways, the study of which will enable us to admire the ingenuity and close attention to details of its inventor, Monsieur N. Riggenbach, and to desire its introduction into India, to which Country it seems eminently suited. The following particulars are obtained from the German Treatise:—

"*Die Drei Rigibahnen und das Zahnrad-system, beschrieben von Roman Abt, Constructeur der Maschinenfabrik Aarau,*" printed at Zürich in 1877.

In converting Foreign into British measures and weights, Rankine's *Conversion Tables*, in his book of "Useful Rules and Tables," have been found to save much labour and to insure accuracy.

Rack-rail Permanent Way.—Rack-rail lines have a similar permanent way to that of ordinary adhesion lines, with the addition of the rack-rail between the two outer carrying rails. In deciding upon the construction of this central rack-rail the chief endeavour was to obtain a simple form which would admit the teeth of the driving-wheel deep into the rack.

Rack Teeth.—Life size details of these will be seen in *Figs.* 1 and 2 of *Plate* I.; the former figure gives a section of a tooth where the cog-

driving wheel grips it, and the latter where the tooth enters the cheek bars of the rack-rail. The teeth are cut from rolled wrought-iron bars, and the ends which enter the cheek bars of the rack are turned in a lathe and rivetted to them cold. The maximum tooth pressure has been taken at 6 tons. Using the formula

$$\frac{Pl}{19} = \frac{bh^2}{c} K$$

we obtain the pressure $K = \frac{Pl}{2\,bh^2}$

where P = 6 tons.

l = 5 inches.

b = 1$\frac{1}{2}$ "

h = (mean of $\frac{2 + 1\frac{1}{2}}{2}$)

Hence $K = \frac{6 \times 5}{2 \times 1\frac{1}{2} \times (1\frac{3}{4})^2} = \frac{15}{3 \times 3\frac{1}{16}} = \frac{160}{49} = 3\frac{1}{4}$ tons per square inch,

which is one-seventh of the breaking weight, as will be seen on the opposite page.

Rack-Rail.—Figs. 3 and 4 of *Plate* I., are sections of the rack-rail, which is entirely of wrought-iron and in lengths of $3\frac{1}{4}$ (3·27) yards. The clear length of each rack tooth is nearly 5 (4·9) inches, and the width of the cog-driving wheel is nearly 4 (3·978) inches; there is thus a play on either side of the wheel when engaging in the rack of nearly half (·468) an inch. In the Vitznau-Rigi Line, which is as steep as 1 in 4, each locomotive has two pairs of angular jaws which embrace the upper flanges projecting on each side of the central rack-rail: in the event of the wheels being lifted off the rails by a hard substance getting between the teeth of the rack, these jaws would catch against the flanges and hold the vehicle in its place. (See *Fig.* 3, *Plate* I.) This precaution is considered unnecessary in rack-rail lines with gradients easier than 1 in 10. Hence the section shown in *Fig.* 4, *Plate* I., where the upper flanges are reduced to a little over one inch.

The lowest tooth on the incline in each length of the rack-rail is obviously the most liable to be forced out. For this reason the cheek plate joints are made unequal (see *r*, *s*, in the three figures of *Plate* II.) The pitch or distance apart of the rack teeth from centre to centre is 3·9 (or nearly 4) inches. In *Fig.* 2, *Plate* I., it is seen that the thickness of the rack tooth shank, where it enters the cheek bars, is 1·65

inches: a play for contraction and expansion of ·08 of an inch is allowed in the slot of the cheek bar, which the tooth enters: hence a balance of 2·17 inches is left (1·65 + ·08 + 2·17 = 3·9 inches) of which one end of each rack bar has ·81 inches, and the other 1·36 inches. Before constructing the first rack-rail very careful experiments on this point were made. The joint was first placed in the centre of the two teeth, leaving $\frac{2·17}{2} = 1·085$ inches of solid iron: the tooth was then torn out by a weight of 26 tons. 1·95 or nearly 2 inches of solid iron was next placed beneath the tooth, when this thickness split with 42 tons. Hence the resisting power of the iron was fond t o be in round numbers 51,000 lbs., or 22¾ tons per square inch.

Permanent Way.—Plates II. and III. give longitudinal and cross-sections of three types of rack-rail permanent way.

First type. Rack-rail level with bearing rails.—Figs. 1 in each Plate is ti at of the Vitznau-Rigi line. *a, a,* are the longitudinal timbers; *b, b,* the smooth carrying rails or normal running way. In the centre between these latter is the rack-rail lying directly on the cross-sleepers. The two outer longitudinal timbers are notched into the cross-sleepers and bolted to them by strong screws. This stiff framing is then imbedded in ballast and packed in the usual way. As a security against any possible slipping of the framing on such a steep gradient as 1 in 4, it is also strongly secured at intervals of 250 or 300 feet to masonry foundations built five feet deep into the solid ground below. This security is not required on easier gradients. A short time back these longitudinal pine-wood sleepers were replaced by others of wrought-iron. On gradients easier than 1 in 20 these additional longitudinal sleepers can be dispensed with: even the Wasseralfingen line of 1 in 13 has no longitudinal sleepers. The central rack-rail is fastened to the cross-sleepers in three ways; (i), the rack-rail lengths are jointed with horizontal fish-plates under both of the lower flanges (see *m, n, Fig.* 1, *Plate* II.) of the rack-rail cheek bars: these fish-plates are attached to the cheek bars by six screws of which two (*p, q, Fig.* 1, *Plate* II.) pass into the cross-sleeper; (ii), the lower flanges of the rack-rail cheek bars are fastened to the three intermediate cross-sleepers by screws; and (iii), at *x, Fig.* 1, *Plate* II., angle-irons are rivetted to the lower flanges of the rack-rail and fastened to the up gradient side of each of these intermediate cross-sleepers.

Second Type. Rack-rail raised above bearing rails by longitudinal timbers.—Where a rack-rail line has to be used all the year round, or in conjunction with other smooth rail or adhesion lines, it is necessary to raise the central rack-rail above the side carrying rails, so as to prevent its being choked in winter by snow or ice, or to enable the cog-driving wheel, by being elevated, to travel safely over the permanent way of the other adhesion lines. This is effected by laying between the side rails two longitudinal timbers (*a*, *a*, *Fig.* 2, *Plate* III.) to which the rack-rail is fastened. At each joint of the rack-rail which requires 12 screws (see *Fig.* 2, *Plate* II.) the four outer pass both through the lower flanges of the rack-rail cheek bars and through the longitudinal sleepers. The heads of the other eight fastenings, together with the fish-plates themselves, are countersunk into the longitudinal timbers. A channel (*m*, *n*, *o*, *p*, *Fig.* 2, *Plate* III.) $8\frac{1}{2}$ inches deep runs along the whole length of the permanent way. The centre of the rack teeth are thus $2\frac{3}{4}$ inches above the top of the side bearing rails. This construction has succeeded: such lines have been worked at all seasons, and inclement weather at high altitudes has had no greater effect on them than on ordinary adhesion lines.

Third Type. Rack-rail raised above bearing rails by cast-iron chairs.—The last improvement effected in the permanent way was to substitute cast-iron chairs for the elevated longitudinal timbers of the second type. *Figs.* 3 in *Plates* II. and III. illustrate this third type. The chairs will be found figured in *Plate* IV. Four screws (*a*, *b*, *c*, *d*, *Fig.* 1, *Plate* IV.) secure these chairs to the cross-sleepers and a lower rib (*g*, *g*, *Figs.* 2 and 3) prevents these screws from being too severely strained. Three upper ribs (*h*, *h*, *h*, *Figs.* 2 and 3) accurately fit in between the cheek bars of the rack-rail and prevent lateral movement. The chairs are placed $9\frac{3}{4}$ feet apart from centre to centre immediately under the joints of the rack-rail. Each length of the rack-rail is secured to the chairs by 4 screws, 2 at each end (see *Fig.* 3, *Plates* II. and III.); the 2 screws at the upper gradient end of the joint allow a play for contraction and expansion; at the lower gradient end of the joint an angle-iron (*x*, *Fig.* 3, *Plate* II.) further unites each chair to the lower flanges of the rack-rail cheeks. Between the two intermediate cross-sleepers and the rack-rail are inserted wooden blocks secured by screws (*a*, *b*, *Fig.* 3, *Plate* II.) The accompanying Table (No. I.) gives details of the permanent way of seven Rack-Railways.

RACK-RAIL ENTRANCES.—These are placed where the rack-rail and

TABLE No. 1.

Principal Dimensions of the Permanent Ways of seven of the Rack-Railways.

Name of Railway	Gauge	Length	Maximum Gradient	Mean Gradient	Radius of sharpest curve	Line when begun	Weight per foot run: Rack-rail cheek bars	Weight per foot run: Rack teeth	Weight per foot run: Centre fastenings	Weight per foot run: Rack-rail complete	Foundation of the Rack-rail	Nature of the Longitudinal Fastenings	Carrying Rails: Weight per running yard: Rail in	Carrying Rails: Weight per running yard: Fastenings	Carrying Rails: Height	Remarks
		yards			ft.		lbs	lbs.	lbs	lbs.			lbs.	lbs.	in.	
Ostermundingen,	4′ 8″½	612	1 in 10	1 in 10	straight	1870	11	9	2	39	Longitudinal timbers.	Side fish-plates held by two bolts.	64½	5	4·68	Locomotives of the mixed system
		miles.														
Vitznau-Rigi,	4′ 8″⅓	4·34	1 in 4	1 in 5¼	590	1871	12½	8½	2¼	37¼	Cross-sleepers	Fish-plates between the lower flanges of the rack check bars.	33½	3	3½	Locomotives of the single system with vertical boilers
Kahlenberg,	4′ 8″½	3·2	1 in 10	1 in 18	590	1874	12¼	8½	2¼	37¼	Do.,	Do. do.,	40¼	3·6	3½	Locomotives of the single system with horizontal boilers
Schwabenberg,	4′ 8″½	1·87	1 in 9¾	1 in 10¼	590	1874	12¼	8½	2¼	37¼	Do.,	Do. do.,	40¼	3·6	3½	
Arth-Rigi,	4′ 8″½	6·1	1 in 4¾	1 in 7½	590	1875	12¼	8½	2¼	37¼	Do.,	Do. do.,	40¼	3·6	3½	
Rorschach-Heiden	4′ 8″½	3·42	1 in 11	1 in 14	788	1875	11½	8½	2¼	35½	Two longitudinal sleepers.	Do. do.,	40¼	3·6	3½	Locomotives of the single system, with horizontal boilers
		ft.														
Wasseralfingen,	3·28	5·13	1 in 12½	1 in 12¾	1,312	1876	11½	6¼	¾	31½	Cast-iron chairs.	Cast-iron chairs,	64½	5	3¾	Each cast-iron chair weighs 34 lbs. Locomotives of the mixed system
Total miles, ...		24·41														

adhesion lines join, in order to facilitate the passage of the cog-wheel locomotive from the one to the other. In Vol. VI. of *Indian Engineering* [Second Series], page 237, this arrangement was thus explained :—

"In advance of the regular fixed central rack-rail is a piece of central rail resting on a powerful elastic spring, the rungs of the rail ladder being at a greater distance apart than in the regular rail and diminishing by degrees in distance until the normal distance between the rungs is obtained. The toothed driving-wheel of the locomotive, on reaching the first rung or cog of the advance rail, presses down the elastic spring, and its tooth drops down somewhere between the first and second cogs ; by this means the teeth of the driving-wheel, as it moves forward, are guided by degrees over the cogs of the elastic rail into the normal fixed rail, on reaching which the driving-wheel has adjusted itself to its proper position with reference to the central rack-rail, and its teeth work into the rungs of the ladder without a jar."

Plate V. illustrates this arrangement. In *Fig.* 3 of *Plate* V., at *g*, is shown a triple hinge, connecting the advance portion of the rack-rail with the normal rack-rail. The advance portion rests on two springs, one the spiral spring (*m*, *n*, *Figs.* 1 and 3), and the other the cross-spring (*a*, *b*, *Figs.* 2 and 3). The space between every two teeth of the advance rack-rail is ·079 of an inch greater than it is in the regular rack-rail. And *p*, *q*, in *Figs.* 1 and 3, are guide arms to prevent lateral motion.

Turn-Table Switches.—To shift vehicles from one line to another a special contrivance is necessary, the ordinary switches being rendered inapplicable by the rack-rail. This apparatus will be understood from *Plate* VI. It is essentially a segment of a turn-table. This turn-table or platform carries two complete rack lines, having curves with a radius of 590 feet. They carry an entire train. Their whole length is 44¼ and breadth 35½ feet. The turning is performed by means of a crab (*a*, *a*, *Fig.* 1, *Plate* VI.) which works through shafting *b*, *b*, the toothed wheels, *c*, *c*, into the rack-rails *d*, *e* ; *d*, *e*. The entire turn-table rests on thirteen axles, and is assisted by three rollers (*see* left hand *Fig.* 1) fixed in the enclosing wall, these rollers being required as the platform is on a gradient of 1 in 16⅔.

Rolling Stock.—*Locomotives.* In addition to the illustrations which have appeared at page 219 of Vol. VI. of *Indian Engineering*, [Second Series], we give on *Plate* VII. a horizontal section (at the centre of the cylinders and wheel axles) of a cog-wheel locomotive used on the Ostermundingen line. Its cog-wheel axles are *m*, *p*, *q*, *m*, and *n*, *z*, *n*. The driving-wheel axle which is used on smooth rail lines is *a*, *a*. The con-

nection of this axle with the cylinders is made and broken by means of the clutches at *K*, *K*. The axle *a*, *a*, is a double axle; the inner one is of steel and bears firmly wedged on it the two cranks *b*, *c*; *b*, *c*; the outer axle is of wrought-iron and carries the two driving-wheels *T*, *T*. The details of the arrangement at *K*, *K* are given in *Plate* VIII. The spiral axle *W* carries at its extremities screws which communicate motion to the double lever *W*, *Y*, *Z*; *W*, *Y*, *Z* on its fulcrum *Y*, *Y*. This double lever is connected at one end (*W*) with the spiral axle, and at the other end with the clutch K by means of screws. Through the smooth bevel gearing at V the spiral axle *W* is turned and the double spring lever *W*, *Y*, *Z*; *W*, *Y Z*, loosened or tightened as desired, thus communicating a corresponding loosening or tightening motion to the clutch at *K*.

It has been found that the tires of the carrying wheels of a cog-wheel locomotive wear away by rolling friction, hence diminishing their diameter; while the circumference of the cog-driving wheel remains *in statu quo*, there being no appreciable friction on the heads of the teeth. The diameter of the carrying-wheels is therefore made one-fourth of an inch longer than required by the diameter of the cog-driving wheel. Thus when the wheels are new the evil is at its maximum in one direction; and the evil diminishes until the driving and carrying-wheels are of the right relative diameters, when their condition is perfect; and then the evil increases to a certain point in the other direction by the diminishing diameter of the carrying-wheels until new tires have to be provided. Let us now enquire into the extent of this imperfection. The adhesion weight of the Wasseralfingen locomotive is $10\frac{3}{4}$ tons. Taking the coefficient of friction at $\frac{1}{7}$th, the tangential force will thus be 3,454 lbs. The wheel circumference is 96 inches. Hence this locomotive performs a mechanical work per inch of wheel circumference of 36 lbs. And as the circumference of the carrying-wheel is three-fourths of an inch longer than that of the cog-driving-wheel the whole excess of mechanical work will be $36 \times \frac{3}{4} = 27$ lbs. per revolution too much; which, by means of the couplings and other connections can have no appreciable retarding effect on the train. The whole mechanical work by the toothed driving-wheel in the same portion of time with a tooth pressure of 6,600 lbs. is 16 lbs., or a maximum labour loss of nearly half per cent. But as the tires wear down until the diameters of the driving and bearing-wheels are equal, when there is no loss, and then wear down still further until the diameter of the driving is

greater than that of the carrying-wheels giving a loss in another direction, the average loss may be taken at one-fourth per cent.

Table No. II. gives the dimensions of seven types of cog-wheel locomotives.

Locomotive Performances.

Let G = total weight of the train in tons.

x = the gradient of the line.

a and b = two constants, their values varying according to the resistance.

v = the train speed in miles per hour.

k = a coefficient giving the increased resistance on curves.

W = the entire train resistance.

Then $W = G\left[\frac{x}{1000} + (a + b\,v)\,k\right]$, the resistance of the air and wind being omitted.

The value of the constants may be taken as—

$a = \cdot0017$

$b = \cdot00015$.

The value of the coefficient k varies, as it depends on the relative position of the wheels, of the axles, and of the couplings; but we will take it at—

On straight portions and up to curves of	2,624	feet radius, let us say	$k =$	1·00
On curves of	1,968	,, ,, ,,	$k =$	1·30
,, ,, ,,	1,312	,, ,, ,,	$k =$	1·90
,, ,, ,,	984	,, ,, ,,	$k =$	2·25
,, ,, ,,	820	,, ,, ,,	$k =$	2·50
,, ,, ,,	656	,, ,, ,,	$k =$	2·80
,, ,, ,,	590	,, ,, ,,	$k =$	3·00

The cog-wheel locomotives exert a tooth pressure of 6 tons, and travel at the rate of five miles an hour on curves of 590 feet radius. Hence in the formula

$$G = \frac{W}{\frac{x}{1000} + (a + b\,v)\,k}$$

$W = 6$; $a = \cdot0017$; $b = \cdot00015$;

$v = 5$; and $k = 3$.

$$\text{Therefore } G = \frac{6}{\frac{x}{1000} + \cdot00735} = \frac{6000}{x + 7{\cdot}35}$$

Giving different values to x (the gradient of the line) from 0 or dead level up to 1 in 4, we obtain the different train weights drawn by the locomotive. These are graphically represented on *Plate* IX., where the gradients are the abscissæ and the train weights the ordinates, the locomotive weights being below and the train weights above the horizontal axis *A*, *A*. *Plate* IX. also shows, for the sake of comparison, in a similar way the performances of a tender locomotive on the Engerth system as used on the Semmering, and those of a tender locomotive on the Uetliberg.

The Semmering Line has curves of 590 feet radius, and the trains on it travel at the rate of $10\frac{1}{2}$ miles an hour on a gradient of 1 in 40. Their locomotives have a total weight of 66 tons, of which $19\frac{1}{2}$ tons fall on the two axles of the tender; hence the adhesion weight is $46\frac{1}{2}$ tons. The drawing power of an ordinary locomotive is found by multiplying the adhesion weight into the coefficient of friction which is on an average $\frac{1}{7}$th, and in favourable circumstances $\frac{1}{5}$. The Semmering locomotive hence gives a drawing power of from $\frac{46{\cdot}5}{7} = 6{\cdot}65$ tons to $\frac{46{\cdot}5}{5} = 9{\cdot}3$ tons. As before,

$$G = \frac{6{\cdot}65 \text{ or } 9{\cdot}3}{\frac{x}{1000} + {\cdot}010725} = \frac{6650 \text{ or } 9300}{x + 9{\cdot}825}$$

Inserting the values of x from 0 up to 1 in 4, we obtain the performances on these different gradients. These are shown on *Plate* IX. in yellow and brown lines.

Each of the Uetliberg locomotives, with 3 coupled axles, weigh 25 tons, all available for adhesion. Hence $\frac{25}{7} = 3{\cdot}57$ tons, and $\frac{25}{5} = 5$ tons. The train speed on curves of 590 feet radius is $12\frac{1}{2}$ miles.

$$\text{Hence } G = \frac{3{\cdot}57 \text{ or } 5{\cdot}00}{\frac{x}{1000} + {\cdot}010725} = \frac{3570 \text{ or } 5000}{x + 10{\cdot}725}$$

Substituting as before the different values of x, we obtain the blue and red curves in *Plate* IX.

Hence we observe from *Plate* IX. that on a gradient of 1 in 25 the Semmering locomotive (blue line) is only just able to drag itself along, and on steeper grades it cannot even do that.

On *Plate* IX. by marking off the ordinates on the right hand vertical line, and from it towards the left hand marking the abscissæ on the upper horizontal line the gradients increasing from right to left, we obtain

curves showing the ratio of the weights drawn to the weights of the locomotive, the quotient of the former divided by the latter being shown by the coloured curves.

Some of the results of the readings of the curves from *Plate* IX. may be shown in the following Table:—

Weights	Cog-wheel Locomotive	Uetliberg Locomotive	Semmering Locomotive
Train tons exclusive of locomotive.	*Continuously.*	*Under favourable circumstances.*	
50	1 in 13	1 in 10	1 in 30
100	1 in 23	1 in 14	1 in 50
200	1 in 50	1 in 33	1 in 100
300	1 in 83	1 in 60	1 in 200
Train weights in terms of the weights of the locomotive.			
Once its own weight, ..	1 in 6	1 in 5⅔	1 in 40
Five times its own weight, ..	1 in 20½	1 in 20	1 in 200
Ten times its own weight, ..	1 in 42	1 in 44	nowhere
Twenty times its own weight, ..	1 in 84	1 in 100	nowhere
Thirty times its own weight, ..	1 in 160	1 in 200	nowhere

A cog-wheel locomotive at Wasseralfingen on a metre gauge weighs 11 tons, and on a gradient of 1 in 12¾ draws a train weighing 28 tons, or 2¾ times its own weight; whereas an Uetliberg locomotive weighing 25 tons on 1 in 14¼ can only draw a train of its own weight.

WEAR OF TEETH AND DURATION OF RACK-RAIL.—The results obtained from fourteen cog-wheel locomotives show that in a locomotive giving a tooth pressure of 6 tons, the average wear on the teeth is—

·00000003761 of an inch at every touch.

The wheel-circumference is 10½ feet and the maximum allowable wear ·2358 of an inch, which wear will be reached after the locomotive has run

$$\frac{\text{·2358 in.} \times 10\tfrac{1}{2} \text{ ft.}}{\text{·00000003761 in.}} = 65734330 \text{ feet.}$$

$$= 12450 \text{ miles.}$$

Experience has shown that the bars of the rack-rail wear out in the same ratio as the cogs of the driving-wheel; but here a maximum wear of only ·1189 of an inch can be allowed. Hence the teeth of the rack-bars must be renewed after

$$\frac{\cdot 1189}{\cdot 00000003761} = 3135736 \text{ trains}$$

have passed over the line. In the rack-rail system the smooth side carrying rails are not only cheaper at first but also cost less in repair than they do on ordinary adhesion lines. This is because the pressure on them is never greater than 4¼ tons, and because no break is ever applied to the smooth carrying wheels which run on loose axles.

Passenger Carriages.—In manufacturing these every care was taken to reduce the weight of each carriage, and this has been done although each carriage possesses a cog-wheel brake. On ordinary adhesion lines a carriage on two axles weighs at least 440 lbs. dead weight per seat, and sometimes as much as 911 lbs. But on the Vitznau Rack-Rail Line this dead weight is only 163 and 194 lbs. *Plate* X. gives a graphic representation of the carriage resistances on one rack-rail and on three adhesion lines. The gradients are drawn as abscissæ, and the resistances as ordinates. The right hand lines give the resistances per carriage, and the left hand lines those per seat, in a similar manner to *Plate* IX. These resistances have been calculated from the following formulæ, in which the weight of the carriage is alone taken into consideration, the other resistances being almost identical in the four cases which are compared.

Resistance made by weight $w = P \times x$ lbs. .....(i),

and No. of lbs. pulling on each seat $a = \frac{P \times x}{Z}$ .....(ii),

where P = weight of empty carriages in lbs.,

x = the gradient,

Z = the number of seats in each carriage.

Applying these formulæ:—On a rack-rail incline of 1 in 40 a Vitznau-Rigi carriage having 54 seats weighing 8,860 lbs. when empty, causes in consequence of this weight a resistance of $\frac{8860}{40} = 220$ lbs. according to formula (i); or a little over 4 lbs. per seat by formula (ii). [*See* black line on *Plate* X.] A 3rd class carriage on four axles of the Swiss Central Line having 72 seats and weighing when empty 11¼ tons, or 24,750 lbs. has similarly a resistance of $\frac{24750}{40} = 618$ lbs., or $8\frac{3}{4}$ lbs., per seat.

[*See* red line on *Plate* X.] A double carriage with 1st and 2nd class apartments on the Swiss North-East Line on four axles with 52 seats and a dead weight of 28,050 lbs. gives a resistance of $\frac{28050}{40} = 701\frac{1}{4}$ lbs., or $13\frac{1}{4}$ lbs. per seat. [*See* blue line on *Plate* X.] A double carriage with 1st and 2nd Classes on the same line on two axles with 26 seats and 23,650 lbs. dead weight gives a resistance per carriage of $\frac{23650}{40} = 592$ lbs., or of 22 lbs. per seat. [*See* yellow line, *Plate* X.]

Plate XI. illustrates a *Goods' Truck*: and Table III. gives the details and dimensions of the Rolling Stock.

Working Expenses.—Table IV. gives details of the annual working expenses of three of the Rack-Rail Lines in Switzerland.

Fuel, Grease and Oil.—In 1875 the Vitznau-Rigi Line comsumed

773	tons of coal, or per locomotive mile,	.. ..	102 lbs.
$2\frac{1}{4}$	„ cog-wheel grease, or per locomotive mile,		0·30 „
$4\frac{3}{4}$	„ engine oil, or per locomotive mile,	..	0·64 „

The mountain portion of the Arth-Rigi Line consumed

$411\frac{1}{4}$	tons of coal, or per locomotive mile,	.. ..	$79\frac{3}{4}$ lbs.
$2\frac{1}{4}$	„ cog-wheel grease, or per locomotive mile,		0·42 „
5	„ engine oil, or per locomotive mile,	..	0·97 „

Stations.—*Plate* XII. illustrates two stations of the 1st and 2nd class.

Numbers	Boilers: Heating Surface: Fire Box	Boilers: Heating Surface: Tubes	Boilers: Heating Surface: Total	Boilers: Fire grate area	Boilers: Pressure of Steam in Boiler	Total length over buffer beams	Weights: Empty	Weights: In working order	Pressure on teeth	Speed in miles per hour	Maximum performance in Horse-Power	Remarks
No	Sq ft	Sq. ft	Sq ft	Sq ft	lbs on the sq. inch	Ft In	Tons	Tons	Tons	Miles	H P	
32	36·27	510·53	546·80	7·86	132·3	23 3½	18	21	5½	3¾ and 5	125 and 185	A double driving-axle for coupling and uncoupling.
84	31·00	597·50	628·50	8 83	147	20 4	10	12½	5½	3 1/16	105	A running axle which is at the same time a cog-wheel axle : the other is a brake-axle.
74	62·86	479·00	541 86	11 2	132 3	21 10¼	13½	16	5¼	6¼	185	The foremost or first running-axle is at the same time also a brake-axle.
74	62·86	479 00	541·86	11·2	132 3	21 10¼	13½	16	5¼	6¼	185	Ditto ditto.
33	62·86	479·00	541·86	11·2	147	21 0	13½	17	6	5	185	Ditto ditto.
33	62 86	479·00	541·86	11·2	147	22 7¾	12½	16	5¼	6¼	185	
75	42·00	227·11	269·11	6·67	132·3	17 2	9¼	11	2⅘	5⅗	95	

TABLE No. III.

Chief Dimensions of the Passenger Carriages and Goods' Trucks of most of the Rack-Railways.

Name of Railway	Number of carriages or trucks	Number of seats per passenger carriage	Wheels: Cog-driving wheel: Diameter in feet	Wheels: Cog-driving wheel: Number of teeth	Wheels: Brake Wheels: Number of wheels	Wheels: Brake Wheels: Diameter in feet	Wheels: Brake Wheels: Breadth	Wheels: Carrying Wheels: Number of wheels	Wheels: Carrying Wheels: Diameter in feet	Axles: Diameter in Inches: Shank in inches	Axles: Diameter in Inches: Naves in inches: Intermediate wheel	Axles: Diameter in Inches: Naves in inches: Brake-wheel	Axles: Diameter in Inches: Naves in inches: Cog-wheel	Entire wheel-base	Inside size of carriage or truck: Length	Inside size of carriage or truck: Breadth	Inside size of carriage or truck: Height	Tare weight	Weight which trucks can bear	Remarks
	No	No	ft	No	No	ft	in	No	ft	in	in	in	in	ft in	ft in	ft in	ft in	tons	tons	
PASSENGER CARRIAGES.																				
Vitznau-Rigi, ...	12	54	2	19	2	1 ft 7 2/3 in	...	4	2 ft 1 2/5 in	3	4 2/5	5	6	13 9 1/3	27 6 3/4	9 4 1/4	6 4 1/2	4	...	All built on the English plan
Kahlenberg, ...	18	54	2	19	2	1 7 2/3	...	4	2 1 2/5	3	4 2/5	5	6	13 9 1/3	26 3	9 4 1/4	6 4 1/2	4 1/2	...	
Schwabenberg, ...	12	54	2	19	2	1 7 2/3	...	4	2 1 2/5	3	4 2/5	5	6	13 9 1/3	26 3	9 4 1/4	6 4 1/2	4 1/2	...	
Arth-Rigi, ...	7	42	2	19	2	1 7 2/3	...	4	2 1 2/5	3	4 2/5	5	6	13 9 1/3	26 3	9 4 1/4	6 4 1/2	4 1/2	...	
Rorschach-Heiden,	9	54	2 1/10	20	2	1 7 2/3	...	4	2 8 1/4	3	4	...	5 1/3	13 9 1/3	25 0	9 4 1/4	6 4 1/2	6	...	Winter carriages
GOODS' TRUCKS.																				
Ostermundingen, ..	8	...	...	...	...	...	...	4	2 10 1/4	3	4 2/5	...	...	7 10 1/2	14 9	8 10 1/4	...	5	10	Platform Trucks
Vitznau-Rigi, ...	4	...	2	19	1	1 7 2/3	3 1/2	4	2 2	4	3 1/2	5	5 1/3	5 11	11 7 1/8	1 11 1/2	1 11 1/2	2 1/2	7 1/2	Open Trucks
Kahlenberg, ...	4	...	2	19	1	1 7 2/3	3 1/2	4	2 1 2/5	4	4 2/5	5	6	9 10	15 6 1/2	7 10 1/2	1 11 1/2	3 1/2	7 1/2	
Schwabenberg, ...	2	...	2	19	1	1 7 2/3	3 1/2	4	2 1 2/5	4	4 2/5	5	6	9 10	15 6 1/2	7 10 1/2	1 11 1/2	3 1/2	7 1/2	
Arth-Rigi, ...	5	...	2	19	1	1 7 2/3	3 1/2	4	2 1 2/5	4	3 1/2	5	5 1/3	9 10	15 6 1/2	7 10 1/2	1 11 1/2	1 1/2	7 1/2	
Rorschach-Heiden,	8	...	2	19	1	1 7 2/3	3 1/2	4	2 8 1/4	3	4	...	5 1/3	9 10	15 6 1/2	7 10 1/2	6 6 1/2	5	7 1/2	Covered Wagons

TABLE No. IV.

Details of the Annual Working expenses on three of the Rack-Rail Lines in Switzerland.

	Vitznau-Rigi Line, 4·3 miles in length.			Arth-Rigi Line, 7 miles in length.			Scheideck Line, 4·2 miles in length.			
	Total cost.	Percentage of whole.	Per mile of Railway.	Total cost.	Percentage of whole.	Per mile of Railway.	Total cost.	Percentage of whole.	Per mile of Railway.	
	£		£	£		£	£		£	
General management, ...	963	12	222	258	8	37	124	9½	29	Per annum.
Line management, ...	1,225	16	282	548	17	79	284	22	68	
Transport Service, ...	1,067	13½	245	494	15	71	223	17½	53	
Locomotive Service, ...	4,589	58½	1,056	1,972	60	285	651	51	156	
	7,844	100	1,805	3,272	100	472	1,282	100	306	
	Per Locomotive mile.		Per mile of Railway.	Per Locomotive mile.		Per mile of Railway.	Per Locomotive mile.		Per mile of Railway.	
	Shillings.		£	Shillings.		£	Shillings.		£	
Receipts, ...	21½		4,182	9⅗		966	6		470	
Expenses, ...	9½		1,805	4⅘		472	4		306	
Profit, ...	12		2,377	4⅘		494	2		164	

DETAILS OF THE RACK-RAIL TEETH, AND CHEEK BARS.

Scale for Figs.* 1 *and* 2, *full size.*—*Figs.* 3 *and* 4, ½ *full size.

FIG. 1.
SECTION OF THE RACK-TOOTH AT AB FIG. 3.

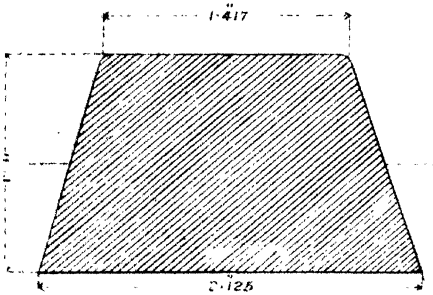


FIG. 2.
SECTION OF THE RACK-TOOTH AT CD FIG. 3.

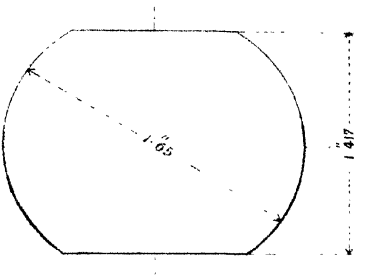


FIG. 3.

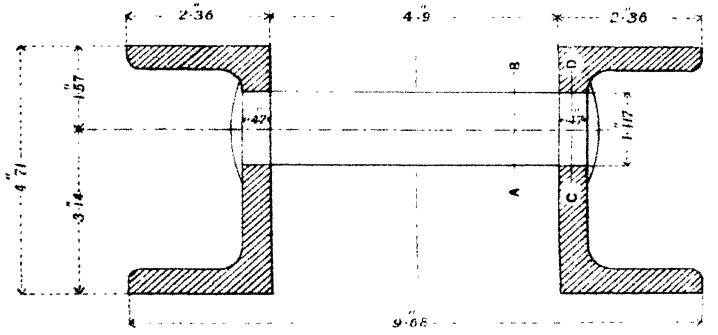
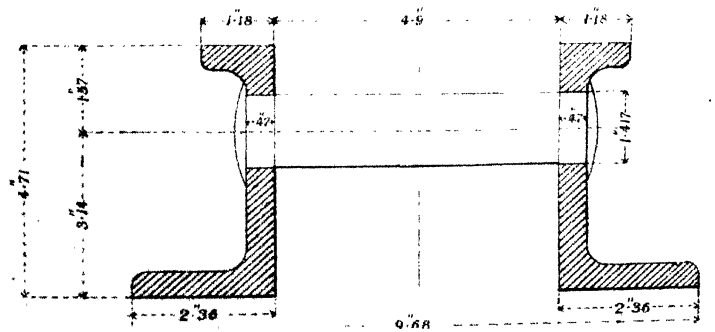


FIG. 4.



LONGITUDINAL SECTIONS OF THREE TYPES OF PERMANE

Scale. $\frac{1}{10}$

FIG. 1.

RACK-RAIL LEVEL WITH BEARI

Direction of Gradient

Longitudinal Section

9'10"

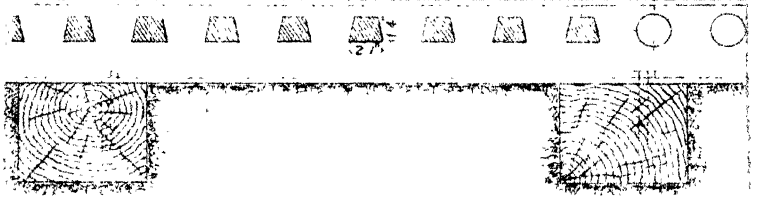


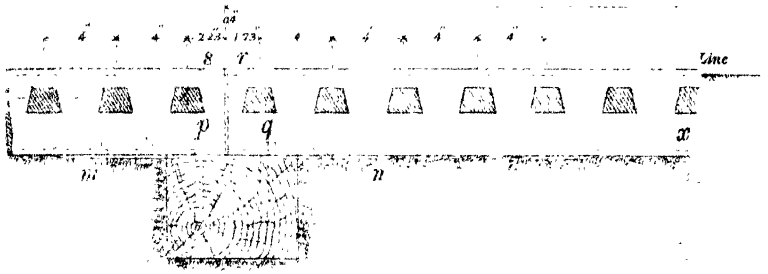
FIG. 2.

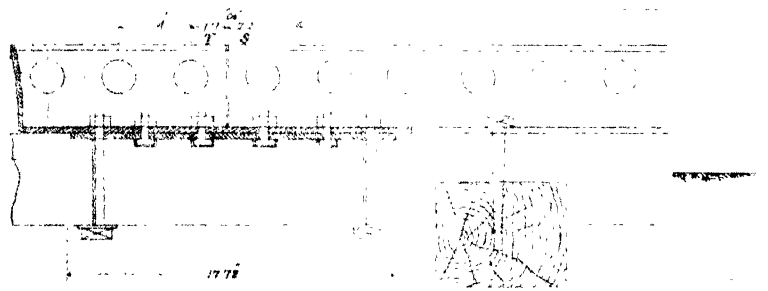
RACK-RAIL RAISED ON WOODEN SLEEPERS ABOVE L

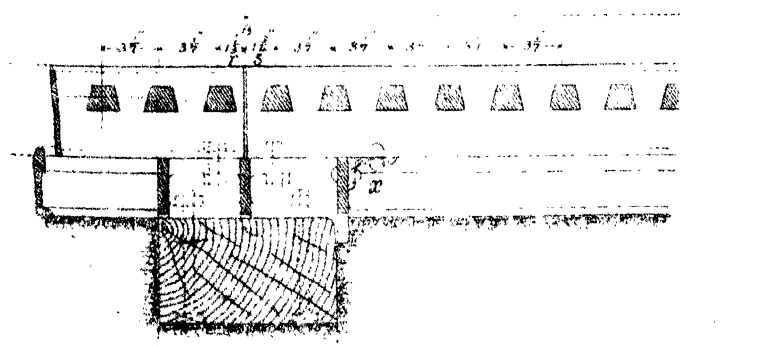
Direction of Gra

9'10"




Line
p
q
x
n


T
S


S
x

PLAN AND SECTIONS OF CAST-IRON CHAIRS FOR CENTRAL RACK-RAIL.

Scale: ½ full size.

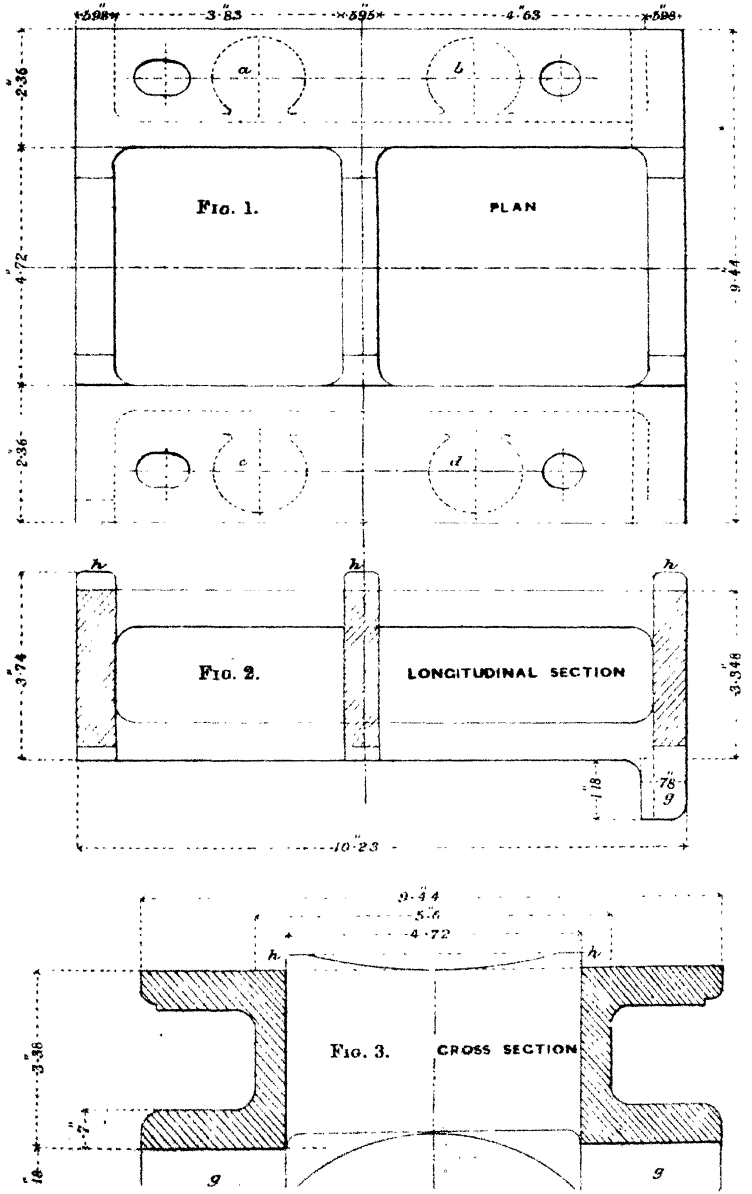
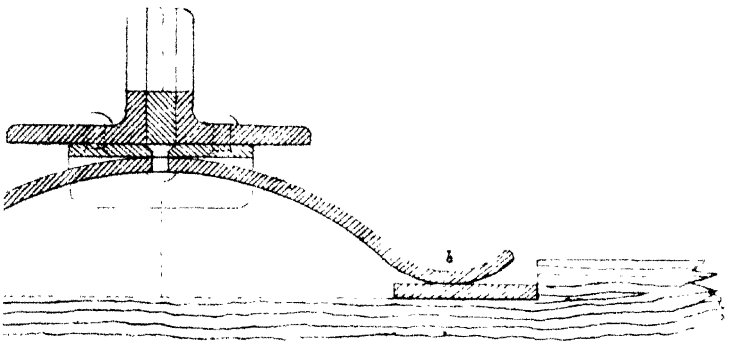
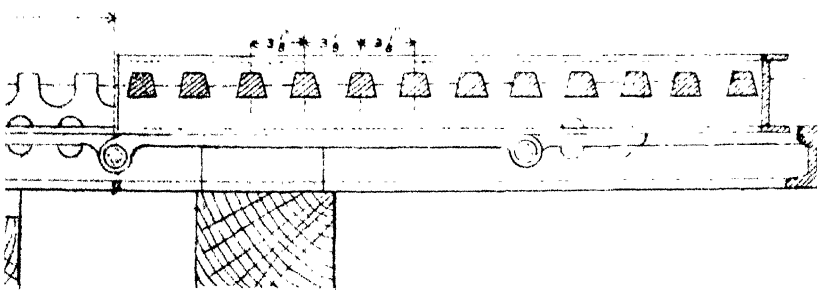


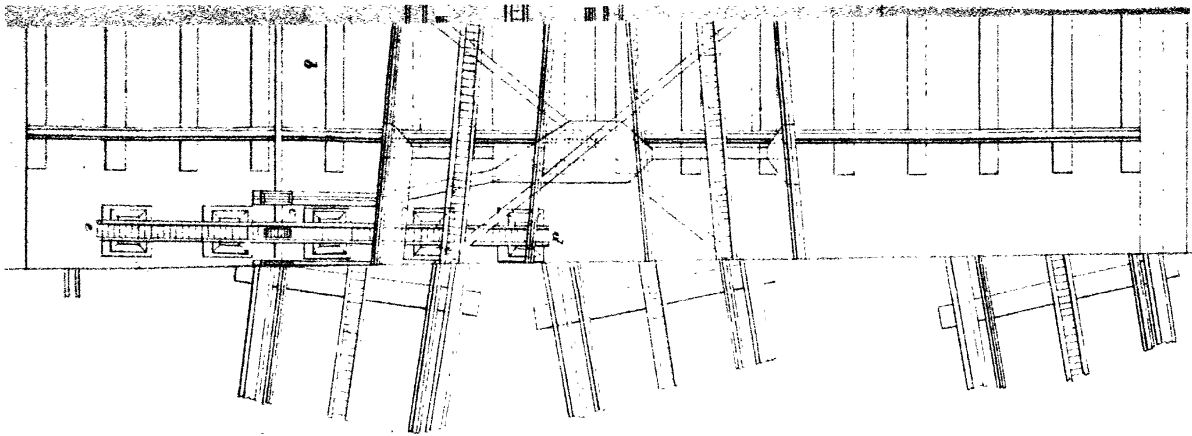
FIG. 2.

RGED SECTION OF SPRING NEAR HINGE

see A, *Fig* 3







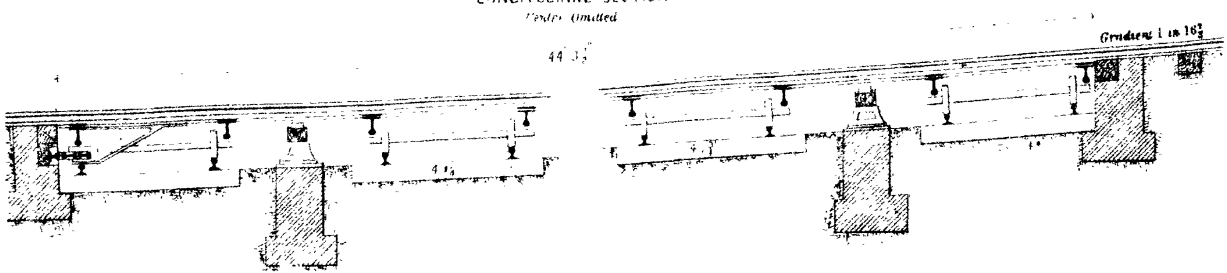
ABLE SWITCHES AT FE

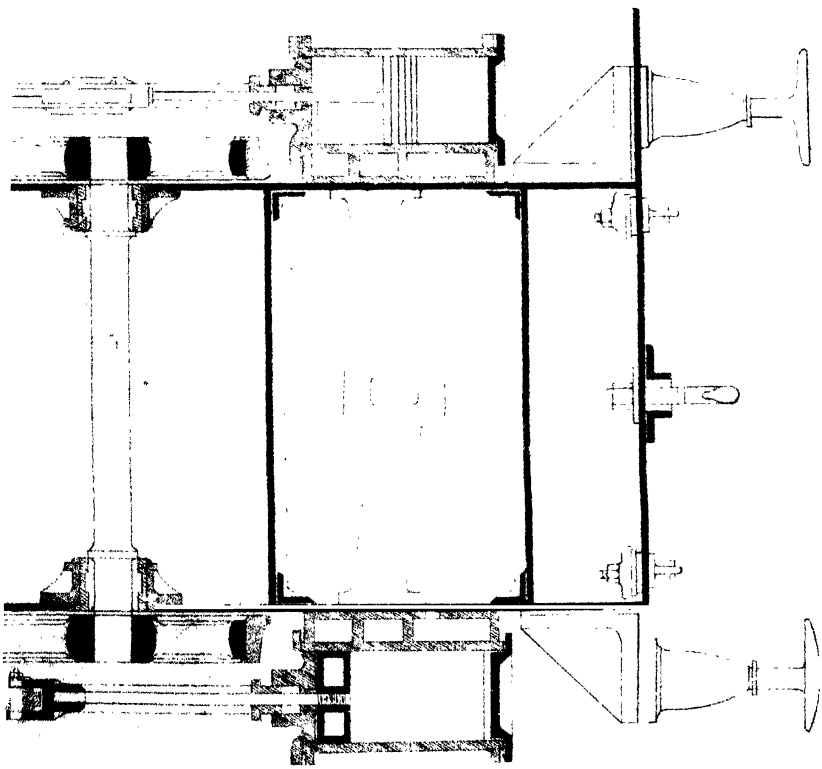
or 5 feet = 1 inch.

FIG. 2.

LONGITUDINAL SECTION

Girders omitted





COG-WHEEL LOCOMOTIVE DETAILS.

Mixed System.

Clutch arrangement for connecting and disconnecting the axle of the adhesion driving wheels with the cylinders.

Scale. $\frac{1}{10}$ *or* $\frac{1}{8}$ *of a foot* = 1 *inch.*

FIG. 1.

SIDE ELEVATION.

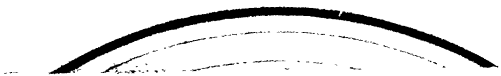
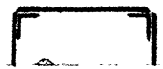
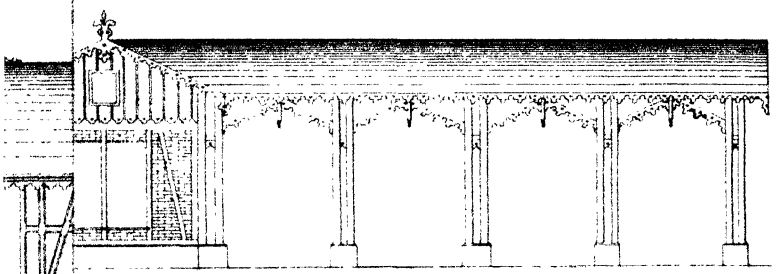


FIG. 2.

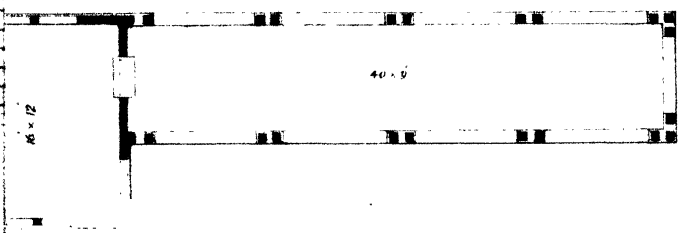
CROSS SECTION.



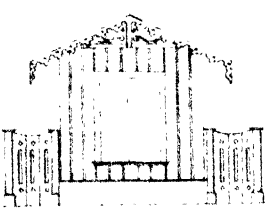
FRONT ELEVATION



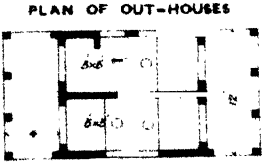
PLAN OF MAIN BUILDING



CROSS SECTION



PLAN OF OUT-HOUSES



No. CCLXVII.

LEAVES FROM A CONSULTING ENGINEER'S NOTE-BOOK.

By Col. Medley, R.E., *Consulting Engineer to Govt. for Railways.*

The Sindh, Punjab and Delhi Railway.

This Railway runs from the Ghazeeabad junction (with the East India Railway) 12 miles from Delhi, *viâ* Meerut, Saharunpore, Umballa, Loodiana, Jullunder and Umritsur to Lahore, and thence to Mooltan, and on to the Shere-Shah Ghât on the Chenab, a total length of 554 miles.

The Sindh Section comprises only the line from Kotree on the Indus to Kurrachee, a length of 110 miles.

The communication between Kotree and Mooltan is for the present maintained by the Indus Steam Flotilla, over a length of 575 miles of river navigation, which will shortly be supplemented or superseded by the opening of the Indus Valley State Railway.

The most important Engineering works on the line are the bridges over the Sutlej, Beas, Jumna, Markunda and Guggur.

All these bridges are of the same class, varying only in details, consisting of a series of wrought-iron lattice girders, 80 to 110 feet span, supported on single well cylinders 12½ feet in external diameter, sunk for a depth of about 40 feet in the sandy beds of the rivers.

The experience of several years has now shown that the general design of these structures is faulty, certainly as far as the large rivers are concerned; 1*st*, Because the numerous piers of the short spans obstruct the waterway too much; 2*nd*, Because the pier cylinders are sunk to an indepth and are not safe from being scoured out; 3*rd*, Because

the single piers are deficient in lateral stability. Stone in enormous quantities has had to be used at a very high cost, both to protect the piers and abutments, and in the construction of groynes for guiding the stream.

The country generally through which the line runs is flat and open; between Lahore and Mooltan it is for a considerable portion of the way a perfect desert, which however only wants water to produce good crops. Between Lahore and Delhi the country is well cultivated and populous.

The Permanent Way consists partly of iron double-headed reversible rails, 68 lbs. to the yard, and partly of steel topped double-headed non-reversible rails, 60 lbs. to the yard. The latter have not worn well; the steel separates from the iron and comes off in flakes; these will gradually be replaced by solid steel rails. The sleepers used are partly deodar and partly Greaves' cast-iron pots, which on this line have answered well.

There is nothing specially noticeable in the Stations, which are (like those of many other Indian lines) deficient in proper accommodation for the 3rd class native passengers. Waiting sheds are however now being erected.

The Locomotives burn coal between Ghazeeabad and Lahore; wood between Lahore and Mooltan. There is nothing specially remarkable about any of the Rolling Stock, except the double-storied 3rd class carriages used for the Lahore and Umritsur local trains.

The following figures give the most important data in reference to the e, for the half-year ending June 30th, 1877:—

Total length, ...	664 miles.
Total Cost including Rolling Stock, ...	£9,558,576
Cost per mile, ...	£14,406

Net profit on Capital (per cent. per annum) 3·4.

For Punjab Section only—Shere Shah to Delhi, 554 miles.

Receipts for half-year ending 30th June, 1877, ..	Rs.	31,77,402
Expenses, ...	„	18,95,391
Percentage of Working expenses to earnings, ..		59·6
Cost per train mile, ...	Rs.	3·02
Receipts per mile of Railway per week, ..	„	220
Number of stations, ...	59	
Average distance apart, ...	9·5 miles.	
Number of Locomotives actually employed,	59	
In working order, Number of Passenger carriages, ..	426	
„ „ Goods' Wagons, ..	1,895	

Number of trains run per day in either direction :—

Mail, ...	1
Local, ...	3
Mixed,..	1
Goods, ...	4 to 6

The following are the principal fares and rates charged on the line : —

Passengers per mile.

		d.
1st class, ...	18 pies	= 2¼
2nd „	9 „	= 1⅛
Intermediate, ...	4½ „	= $\frac{9}{16}$
3rd class, ...	3 and 2¼ „	= ⅜ and $\frac{9}{32}$d.

Goods per mile.

		d.	
Special class,	¼ pie per maund, ...	= ·85	per ton.
1st „	⅓ „	= 1·1	„
2nd „	½ „	= 1·7	„
3rd „	⅔ „	= 2·3	„
4th „	⅚ „	= 2·8	„
5th „	1 „	= 3·4	„

Analysing the Receipts for the half-year, we find them to be as follows :—

Passengers.

	No. carried.	Amount received. RS.
1st class, ...	8,696	71,496
2nd „	23,106	88,265
Intermediate, ...	10,301	20,956
3rd class, ...	12,68,143	9,81,428
Luggage, (ton miles,)	1,99,823	54,435

The average distance travelled by a passenger was 65 miles.

Goods.

	Tons lifted.	Receipts. RS.
Special, ...	1,57,576	7,23,136
1st class, ...	26,240	2,53,242
2nd „	17,792	2,56,780
3rd „	9,130	1,71,685
4th „	2,084	48,666
5th „	1,037	25,812

The average distance travelled by a ton of Goods was 149 miles.

The value of the Goods Traffic : Passenger Traffic :: 4 : 3 nearly.

Analysing the Expenditure for the same half-year, we find the division to be—

	RS.
Maintenance, ...	7,03,234 per mile.
Haulage, ...	6,60,391 „
Working, ...	5,31,766 „

The cost of maintenance was exceptionably high during the half-year, as it included part of the charges for the repair of a serious break in the Sutlej Bridge.

The cost of Haulage (*i. e.*, Locomotive and Carriage expenses) on this line is always high on account of the heavy cost of coal, which has to be brought from a distance of 900 miles by railway.

Working of course includes Establishment and Traffic charges.

The principal Staples carried over the whole line are as follows in order of their importance :—

	Tons.	Receipts. Rs.
Food Grains, ...	1,30,507	5,88,059
Oil-seeds, ...	40,422	3,69,803
Piece Goods, ...	7,465	1,63,510
Sugar, ...	13,347	1,57,612
Cotton, ...	7,250	1,25,867
Metals, ...	8,703	1,04,074
Wool, ...	3,922	97,041
Fruits, fresh and dried, ...	3,344	43,327
Salt, ...	8,917	42,410
Hides and horns, ...	2,471	33,213

Besides Railway Materials and Military Stores to a large amount.

From an inspection of the above data it may be noted on this as on other Indian lines—

1st.—That the Goods Traffic is more important than the Passenger Traffic. This is doubtless owing partly to the poverty of the people, partly to the bulk of the population being scattered in villages instead of being concentrated in towns, which of course is due to India being an agricultural, rather than a manufacturing, or commercial, country. But it is also due to the fares for the latter being comparatively higher than the rates for the former, as will be seen by a note further on.

2nd.—The immense importance of the 3rd class passenger traffic as as compared with that of the other classes, the number of 3rd class passengers being 96 per cent. and the receipts 84 per cent. of the whole. This of course is only what might have been expected, but it is only of late years that it has been recognised as a fact to be acted upon.

3rd.—The very great importance of the lowest and cheapest class of Goods as compared with the other classes, the special or lowest class furnishing 73 per cent. of the quantity and 49 per cent. of the whole receipts

from Goods; while the 4th and 5th classes together, being the most valuable intrinsically, furnish less than 2 per cent. in quantity, and only 5 per cent. in earnings, of the whole. It will be seen that the two most important staples are the Edible grains and the Oil seeds, both of which are now largely exported to Europe.

The wheat export trade has sprung up suddenly within the last 3 or 4 years, and under the stimulus of a succession of good harvests here and high prices in Europe, has quite exceeded the carrying capacity of the Rolling Stock which is now being largely increased to meet it. Of course with such a commodity of small intrinsic value, and which has to be carried 1,600 miles to the sea-board, the margin of profit is very small, and any rise in the price here, or fall in the price in Europe, at once affects the trade very sensibly. The area of land suitable for wheat cultivation in the Punjab may, however, be almost indefinitely extended; both climate and soil are favourable; water is the one thing needed, and it is to be hoped that the construction of Irrigation canals down the centres of the Doabs will not be much longer delayed. That, and the immigration of some of the surplus population from the more densely populated parts of the country, appear to be the true remedies against future famine. The expenditure of large sums in irrigation works where the population is already too dense appears to be a mistake, as it is a direct stimulus to still greater fecundity.

India being a poor country and the importance to the Railway of the poorest items of Passenger and Goods' traffic being now conclusively proved by the experience of all the Indian lines, it is good policy to accept these facts and do all that is possible to encourage such traffic so as to make up by number and quantity what is lost in intrinsic value. This consideration points to what are now pretty well recognised as the principles on which the administration of an Indian Railway should be constructed:—

1*st*.—Cheapness of fares and rates, for the people and goods' carried are both essentially poor.

2*nd*.—Cheapness of carriage *to* the rail by the construction of good roads or branch lines.

3*rd*.—Adaptation of stations, carriages and the train service generally to the wants and circumstances of the great bulk of the population.

4*th*.—Speed is so subordinate in importance to economy of transit, especially where fuel is so dear, that it may be said it should practically be regulated simply by the carrying capacity of the line.

1st and 2nd class passenger traffic is carried at little if any profit. The number of 1st class passengers is not susceptible of much increase or decrease, and the fares and accommodation provided* must be settled by other considerations than those which obtain for the 3rd class. This is not so much the case with the 2nd class, which, it is believed, might be considerably increased on most lines by some reduction of fares; it is certainly more elastic than the 1st class. There appears however, to be no adequate reason for the very great difference of fare at present charged to 1st and 2nd class passengers respectively, when there is so little difference in the accommodation provided.

The tendency of late years, after considerable discussion of the subject of 3rd class fares, has been to fix the lowest possible rates. It is now pretty well recognized that the difference in value of money in the two countries is so great that what would be a very low mileage rate for an English labourer or mechanic might easily be a very high rate for an Indian coolie or mistree, and that when the average distance to be travelled is taken into consideration, such a rate would be positively prohibitory. The rate generally adopted on the State lines is 2 pies per mile, and it should certainly be looked upon as a maximum. If the bulk of the population is to be induced to travel, and if they do not, very few of the lines can pay—then a 1 pie rate† will eventually have to be adopted.

If a 6 ton wagon load of grain can be hauled for a mile at a fair profit for 6 pies per ton mile, it is evident that a carriage load of 50 passengers can be hauled the same distance at a greater profit for 1 pie per passenger, for the latter requires less weight to be hauled and costs less to handle. No Indian Railway should lose sight of the fact that passenger traffic pays far better than Goods, but like the latter, it can only be secured by excessively cheap rates.

Much has been done of late years to facilitate the convenience of travelling to the only *paying* class of passengers. They are generally treated with civility and consideration and most of them have now-a-days become experienced travellers, alive to their rights and well able to take care

* Among other improvements lately introduced (on this particular line at least) may be mentioned the adoption of punkahs in first class carriages. The punkah bar runs the whole length of the carriage and is made to oscillate by a simple crank and lever, worked by a coolie seated either in an end compartment, or on a railed platform outside one end of the vehicle.

† That many travellers still go long distances on foot over the roads parallel to the railways, simply because they cannot afford to pay the present fares, may easily be ascertained by observation and enquiry, and so long as this is the case, it is reasonable to conclude that the present fares are too high.

of themselves. Comfortable Waiting Sheds are now provided on most of the lines. Water and refreshments are available at the Stations, the carriages are seldom overcrowded and are fairly lighted, and separate ones are provided for the women. Something still remains to be done in facilitating the procuring of tickets, the ingress and egress into and out of trains, and such arrangements as will induce the better class of natives to pay somewhat more for better accommodation than the million.

Much also remains to be done in devising a better form of carriage for 3rd class passengers, those at present in use being ill-adapted to their purpose by reason of their utter want of convenience for the offices of nature, which on a long journey is a serious matter. It is submitted that the American form of carriage, with end doors and platforms and a central passage, is the only one yet devised to meet this want, and that on this and on other grounds its adoption is deserving of serious consideration.

The arrangements for issuing tickets, especially during great rushes of traffic, are still very defective ; and by causing great delay and discomfort to travellers must to a certain extent choke off traffic. Something has been done on the Sindh, Punjab and Delhi Railway to facilitate matters in this respect, by introducing movable ticket boxes so as to increase the number of booking places at stations. But a simpler and more effectual plan would be, to sell tickets like postage stamps at duly registered offices, which could be used on any day at the traveller's convenience. The only objection made to this is the risk of forgery, but this objection is equally applicable to the case of Stamps or Bank Notes.

The great mass of the population being located in villages, and not concentrated in towns, it is evident that the Stations should be correspondingly arranged, and that small stations at short distances apart are required for the rural population. To encourage the local traffic, the train service should be so arranged that the villagers can run up to the nearest large town on the line in the morning, attend the markets or the courts and return to their homes in the evening. This has lately been carried out to some extent on the Sindh, Punjab and Delhi Railway, nine new road side stations having been opened and convenient local trains established on three sections of the line. It is now proposed still further to increase the number of stations ; and if daily return tickets at reduced fares are issued, it is probable that a very large local traffic would spring up.

In the Goods' Traffic, the State Railways have taken the lead in simplifying the classification of goods which (like the carriages) was simply copied from English practice, by reducing the number of classes from 6 to 4. And seeing (as was shown above) that the two highest classes of Goods form so small a percentage of the whole, the loss by transferring them to the third class would probably be more than recouped by the additional quantity carried, while all simplification of arrangements tends more or less to economy and increase of traffic.

What is still required to increase and develope the goods traffic on as on other Indian lines is—1*st*, An increase of Rolling Stock; 2*nd*, A proper area of covered sheds at the stations so as to protect the Goods from rain and to enable the wagons to be loaded and unloaded conveniently; 3*rd*, In some cases, provision of Warehouses where Goods can be Stored at a fixed charge, while waiting carriage on or off the line.

Another measure for increasing the Goods' Traffic has lately been initiated with considerable success, and that is, the establishment of Railway Offices in towns within a few miles of the line, at which Goods can be received, booked and paid for—and from which they will be carted to the line by the Company. It is hoped that this system will soon be extended so as to include every important town within 30 miles or so off the line.

Of course the system might be extended so as to include passengers also, who should be able to procure their tickets at these local offices and might be conveyed in horse, bullock or camel vans at cheap rates to the station.

In order to develope the traffic properly on this Railway, the following branch lines would seem to be required :—

1.—Umritsur to Puthankote, 70 miles long, to serve the trade and population of the Upper Baree Doab, it would also subserve the traffic with the Hill Station of Dalhousie—and the produce from the Kangra Valley and the adjacent parts of Kashmir.

2.—Jullunder to Hoshyarpore, 25 miles long, bringing the produce of the Kangra Valley to the line.

3.—Loodiana to Ferozepore, 76 miles long, connecting the line with a rich and populous agricultural district and with the important arsenal of Ferozepore.

4.—Umballa to Kalka, 40 miles long, connecting the line with the Hindustan and Thibet road and with Simla.

Besides these, a junction with the Oudh and Rohilkund Railway, by a branch from Saharunpore *viâ* Roorkee to Moradabad, has also been proposed and will doubtless be carried out.

Of the above four lines, the 3rd has been already surveyed and it is proposed to continue it by bridging the Sutlej at Ferozepore and thence effecting a junction with the Lahore and Mooltan line by a branch of 25 miles to Raiwind. Much of the trade which now goes down the Sutlej in boats would it is thought be thus diverted to the rail.

It is believed that all these branches (except No. 4) could be constructed as light, broad-guage lines with 45 lb. rails (limiting the speed to 15 miles an hour,) for £4,000 per mile without, and £5,000 a mile with, Rolling Stock, and that a traffic amounting to Rs. 120 per mile per week could, without doubt, be secured, which would pay 5 per cent. interest on the capital, allowing 60 per cent. for working expenses.

From Lahore northwards, the railway is continued by the Punjab Northern State Railway, which is at present opened for a distance of 100 miles to Jhelum on the narrow or metre guage, the rails for the first 60 miles being laid on the Grand Trunk Road. The new broad-gauge line will however be shortly opened, and will be continued to Rawul Pindee, 68 miles further.

The greatest works in the Lahore and Jhelum line are the bridges over the Ravee, Chenab and Jhelum, the second being the longest in the world. They all consist of iron lattice girders about 150 feet span, carried on 3 cylinder wells of brick masonry sunk 70 feet below the bed.

The Jhelum and Rawul Pindee line will also cross several large streams, and the cuttings and embankments will be of an exceptionally heavy character, the gradients being as steep as 1 in 50.

Branches from Lala Moosa (near Goojerat) to Pind Dádan Khán (the famous salt mines) and thence probably to Shahpore, and from Wuzeerabad to Sealkote, will doubtless before long be projected.

The traffic on the opened portion of the line has developed itself in a very encouraging manner, necessitating 3 long passenger trains each way daily, besides several heavy goods trains. The cheapness of the fares has doubtless had much to do with this, the charge being made by "station distances" and the average rate per mile for a 3rd class passenger being only 1¾ pie. 1st and 2nd class fares are also only half those charged per mile on the Sindh, Punjab and Delhi Railway.

Beyond Rawul Pindee, the line will probably eventually be continued to Attock and Peshawur, the present frontier of the Empire in this direction. Beyond Peshawur, it is not likely that any line to Central Asia will ever be contemplated owing to the extraordinary difficulties of the country. A more promising line would appear to be from Rawul Pindee to Kohat (crossing the Indus at Kooshalgurh) and thence *viâ* Thull to Cabul. But the best and easiest line to Central Asia is doubtless one from the Indus Valley line *viâ* the Bolan Pass to Kandahar and Heerat. It is possible that military or political considerations may urge the construction of either of these lines upon us sooner than merely commercial considerations would otherwise warrant. A military line of railway from Kohat down the whole of our Trans-Indus frontier to Sukkur has even been talked of, and in the event of a great frontier war would doubtless be of first class importance, but the poverty of most of the country and its difficulty in an Engineering point of view, will probably necessitate its being deferred for many years to come.

J. G. M.

No. CCLXVIII.

SHORT NOTES ON MOUNTAIN RAILWAYS FOR INDIA, WITH A DESCRIPTION OF SEDGWICK'S PATENT HYDRAULIC LIFTS FOR HILL STATIONS.

[*Vide* Plate.]

By Capt. W. Sedgwick, R.E., *Temporary Depy. Consulting Engineer for Guaranteed Railways.*

subject of Mountain Railways should be, for many reasons, an interesting one to people in India.

First, because all who have been in the hills must have felt the inconvenience of our present primitive modes of conveying passengers and luggage between the plains and hill stations, since these modes of conveyance by their roughness entail a great amount of discomfort upon all travellers to the hills, and by their slowness and costliness oblige us to abandon the bright and pleasant inner ranges of the Himalayas, and to place our hill sanitaria on the outer ranges where, whenever rain-falls, they are enveloped in the mists which roll up from the plains, and are cheerless and gloomy in the extreme. With the introduction of Mountain Railways which can run straight up any hill side, can penetrate, by going up and down across intervening ridges, to any distance into the interior, and can bring the magnificent sites in the interior of the Himalayas within a few hours' journey of the plains, residence in the hills would lose most of its inconveniences, and would become much more enjoyable and more invigorating than it is now.

Secondly, because there are now in the Himalayas and other hill ranges, locked up for want of the cheap and quick means of transport which Mountain Railways alone can supply, sources of wealth, practically inexhaustible, in the shape of large tracts containing valuable minerals now untouched, of splendid forests, containing timber of great value for all purposes in which woodwork is used, now left to rot on the hillside, and

of millions of acres of ground now uncultivated on which, if areas for forest reserves were set aside, stock and crops of all kinds could be raised in abundance, and work be found for all comers. For on the hills in India climates and soils of all kinds can be found; the temperature varies from Arctic cold on some of the hill tops to Tropical heat in the valleys; the rain-fall from 10 or 20 inches in the inner ranges, and in the north-west to 600 inches on ranges facing the ocean and towards the north-east; and the soil from clay or rich vegetable mould to light sand.

Thirdly, because while there is a dearth of labour in the hills, there are in the plains poor Europeans and Eurasians in plenty wanting work, and natives in millions who are now in many districts pressing so hardly upon the soil that if the principal crops fail but for one year a famine is inevitable, and for these districts consequently further outlets for emigration are urgently required, the more so because the famine relief policy now inaugurated by Government must tend to increase the population in over-populated districts without proportionately increasing the means of production. If the hills were opened up by Mountain Railways, settlers would be able to find markets for their surplus produce, and we should be able to encourage poor Europeans to come to India instead of, as now, deporting them; for then every additional European settled in the hills would be an addition to our strength, by facilitating the formation of a body of militia or volunteer reserves. Also with the hills opened up there would be food and work in the warm valleys and on the lower slopes, where irrigation from mountain streams can always be practised for any number of natives from over-populated or distressed districts, and fodder and grazing ground for cattle.

A famine relief policy must tend to make famines more and more frequent in occurrence, and therefore such a policy must in the end, from very costliness, give way to a famine prevention policy. An old proverb says, "prevention is better than cure," and it is plain that money spent simply in famine relief must tend to impoverish the country, while money rightly spent in famine prevention must tend to enrich it by increasing its productiveness, directly or indirectly. As the rains do not fail altogether on the higher hills in seasons of drought as they do in the plains, it is clear that the hills, if opened up, will be able to play a very important part in famine prevention as well as in famine relief.

Lastly, because we have in India a splendid European army now, scat-

tered over the plains, where its ranks are thinned abnormally by death and by invaliding; whereas if Mountain Railways, in connection with Branch Railways already constructed or projected, were introduced, we should be able, provided that workshops and other important points on our railways were held by detachments of European troops in fortified posts, to concentrate to a great extent our European army in strong positions in the hills, where the men could be kept in vigorous health (medical statistics have shown that European soldiers, if given healthy employment in the hills, will enjoy as good health in India as in any other country in the world), and whence we should be able to strike, in the event of any disturbance occurring, vigorous blows at once at any points threatened, and should not, as perhaps might be the case now, have to waste precious time in collecting a scattered force. The danger of a disturbance on an extensive scale occurring is doubtless not very great just now; but it may be possible that the present generation of natives do not look on our rule as such an unmixed blessing as the last one, more familiar with the oppression and misrule which preceded our advent, did; and it is certain that few natives now, except bankers, bunneahs, and other kindred spirits, have much to lose. Hence when Russia gets near enough to India to send her emissaries over it, it is not likely that India will remain quiet as it is now.

However, it is not to be supposed that Government can afford to lay out all at once large sums in building new barracks, forming military settlements, &c. &c., in the hills, but our many flourishing stations and tea and coffee plantations in the hills show clearly that if Government were to open out gradually main lines of communication with the most important of the hill districts, private enterprise would not be backward in completing the opening up of the districts. Hence if, in addition to constructing Mountain Railways at a few places where they are most wanted, any new barracks required for our troops were in future built in selected positions in the hills instead of in the plains, the rest would follow in time when the revenue is increased, as it must be, by revenue from the districts opened out in the hills.

It is plain, then, that useful employment could be found for Mountain Railways in India; it remains, therefore, to show that such railways can be cheaply constructed, and cheaply and safely worked. And in doing this, experience gained on Mountain Railways in other countries can be

availed of, for the subject of Mountain Railways has attracted a great deal of attention in Europe and America within the last ten years, and many such railways have been constructed on several systems, some of them with complete success, both from a mechanical and from a financial point of view. The different systems of Mountain Railways now in use may be grouped under two classes; *first*, Mountain Railways with locomotives; and *second*, Mountain Railways with ropes.

But in a country such as India, which though populous and naturally fertile is yet now in a very poor and backward state mainly for want of facilities for communication between its labour producing districts and its districts where labour is scarce, and for want of cheap and quick means of carriage for its surplus produce, where consequently cheapness is in all undertakings a most important consideration, and cheap carriage a vital necessity and where water power, which on a hill side is just as effective as steam power, can be cheaply worked and cheaply obtained, wherever there are hills by constructing tanks or diverting streams, it would seem unreasonable to propose to use a power such as steam, the employment of which involves heavy outlay in construction and heavy working expenses. We may therefore dismiss from consideration with a brief notice the systems of Mountain Railways worked by Locomotives, with which Water Power cannot be used and against which, for use on hills in India, as will be seen hereafter at page 21, more formidable objections even than costliness exist, and confine our attention principally to the systems of Mountain Railways worked with Ropes on which Water Power can be employed.

We note, therefore, that there are two systems of Mountain Railways worked by locomotives in use, viz., the Rigi and the Fell, both of which require a central rail of a peculiar form in addition to a pair of ordinary rails, involving great expenditure in the construction of the railroad. In the Rigi system the central rail is in the form of a rack or ladder, and the locomotives have cogged-driving wheels which engage in the rack or ladder, and thus force the locomotive to ascend the incline on which the rails are laid. The Rigi Railway opened in 1871 was the first railway of importance constructed on this system, it is 3½ miles long, has maximum gradients of 1 in 4, is worked at a speed of 3 or 4 miles an hour, and cost, when completed, about £26,400 per mile.—*Vide* Proceedings of Institute of C. E., Vol. 36, page 103; and Roorkee Professional Papers on Indian Engineering, Second Series, Vol. 6, page 227.

In the Fell system the central rail is raised above the side rails and is gripped by pairs of horizontal wheels. The bite of the horizontal wheels increases the adhesion sufficiently to enable an engine weighing 30 tons to take a gross load of 52 tons up an incline of 1 in 12, at a speed of 10 or 12 miles an hour. This system was first used at the Mont Cenis, temporary summit line opened in 1867, which had maximum gradients of 1 in 12, and was laid on an existing carriage road at a cost of about £7,000 per mile.—*See* Proceedings of Institute of C. E., Vol. 26, page 313; also Roorkee Professional Papers on Indian Engineering, page 272, Vol. 4, Second Series.

We can now turn our attention to Mountain Railways with ropes, of which there are two systems in use; *first*, railways with ropes worked by stationary engines, with which loads can be run both up and down inclines; and *second*, railways with ropes worked by self-acting inclines, which are used only to run loads down inclines.

With railways with ropes and stationary engines the carriages are attached to a rope which is coiled round a large drum driven by a stationary engine; by causing the drum to revolve the carriages are wound up or lowered down an incline. The stationary engine can be placed either at the top or the bottom of the incline.

The most important railways recently constructed on this system are the following, viz.:—

First.—The Leopoldsberg Railway near Vienna, which has a rise of 1,125 feet in a length of 2,378 feet, and consequently an average gradient of about 1 in 2. On this railway a passenger car of two stories, capable of carrying 100 persons, is attached to each end of a steel wire-rope, and in addition to the drawing-rope a second rope of the same strength as the drawing-rope is attached to the carriages and passed round a large drum at the head of the incline; if the drawing-rope breaks the second rope holds the carriages until they are brought to a standstill. This railway commenced working in 1873, and is said to have conveyed 300,000 persons in 100 working days.—*Vide* Proceedings of the Institute of C. E., Vol. 41, page 274.

Second.—The Kahlenburgh Rope Railway in the environs of Vienna, opened during the Vienna Exhibition, with maximum gradients of 1 in 3. This line is said to have been a favourite resort for visitors during the exhibition, and to have carried as many as 5,000 persons in a day. It is

stated that the Austrian Government before they allowed this railway, and also a Rope Railway constructed previously at Buda, to be opened, had the wire-drawing-rope cut while the carriages were in motion on the incline several times, and that each time the rope was cut the carriages were stopped immediately by their breaks.

Third.—The Ofner Railway, opened for traffic in 1869, with a gradient of 1 in 1·6, equivalent to an incline of 32 degrees.

Fourth.—The Croix Rousse Rope Railway near Lyons, which has a uniform rise of 1 in 6·25, and a total vertical height of 230 feet. On this railway a train of three cars, carrying a total of 320 passengers, is attached to each end of the rope. The carriages are provided with a clip-break which, by gripping the head of the rail, prevents the wheels from sliding. It is said that 30,000 passengers are often carried in one day on this line.—*Vide* Proceedings of Institute of C. E., Vol. 41, page 275.

Fifth.—The Rope Railway at Pittsburg in America, which has an average rise of 1 in 1·72, equivalent to a slope with about 30 degrees of inclination to the horizon and a vertical height of 364 feet. The carriages on this line travel at the rate of 9 miles an hour.

Sixth.—The mountain section of the Sao Paolo Railway opened in 1869, with gradients of 1 in 9·75, and a total rise of 2,250 feet: curves with radii of 30 to 80 chains are used on this line which is worked by steel wire-ropes, and has clip-breaks of a peculiar form for gripping the top of the rail. The breaks consist of clips in the form of pairs of huge pincers, opened and closed by a bar, with a wheel handle attached to it, and with right and left screw threads alternately on its surface; the bar is passed through holes tapped with right and left screws alternately in the top of the lever arms of the pincers, and four turns of the bar cause the pincers to grip the rail. The break arrangement, when not in use, is suspended in guides over the rail by a counterpoise, and when required for use is lowered on to the rail by the pressure of the foot on a treadle. Round steel wire-ropes are found to last two years on this line. The ropes are supported on rollers fixed to the sleepers at intervals of ten yards on the straights, and of five or seven yards on curves. It is stated that a rope broke once during the first five years after the line was constructed, and that a goods' train, which was within one hundred yards of the top of one of the inclines at the time the rope broke, was pulled up

on that occasion in a distance of 66 feet without any accident.—*Vide* Proceedings of Institute of C. E., Vol. 30, page 29.

Seventh.—The Lausanne and Ouchy Railway, 4,950 feet long, with maximum gradients of 1 in 9, worked by a wire-rope which has a train attached to either end of it, and is passed twice round a drum placed below the level of the rails and driven by two brass Girard Turbines working under a head of 393 feet of water.—*Vide* page 250, Vol. 50 of the Proceedings of the Institution, C. E., Part 14, Session 1876-77.

It will not be out of place to add that a self-acting clip-break, similar to the one in use on the Sao Paolo Railway, is used on a short railway worked by a wire-rope with a gradient of 1 in $1\frac{1}{2}$, and an incline of 3,300 feet in length, leading down to the Botallack mine in Cornwall. In this case the tail end of the rope is attached to a draw-bar, and if the rope breaks a spring causes the clip to grip the rail; the pressure can be increased, if necessary, by the man in charge of the train with the aid of a lever. It is stated that the rope has broken on two occasions during a period of seven years since these breaks were fitted, and that on both occasions the wagons were brought up immediately by the breaks without accident and without difficulty. On this railway iron wire-ropes are said to stand eight years' continuous wear.—*Vide* Proceedings of the Institute of C. E., Vol. 30, page 74.

It may also be added that at the Adalbert Shaft of the Pribram mine in Bohemia a stationary engine raises loads of one ton each, exclusive of the weight of the cage, from a depth of 3,673 feet in one stage with a steel wire-rope. About 112,000 trips are made annually at a speed of nearly 14 miles per hour, and the ropes are found to stand two years' continuous wear.—*Vide* Proceedings of Institute of C. E., Vol. 41, page 270.

Rope Railways with self-acting inclines have long been in use at mines or quarries on hillsides. With this system the carriages are attached to an endless rope passed round drums at the top and bottom of an incline, and supported throughout its length on rollers or pullies. Wagons loaded at the top of the incline descend the incline by gravity, and in their descent draw empty wagons attached to the other side of the rope up the incline.

The most important railway, of recent construction, worked on this system, is the one opened in 1873 to connect the Styrian Iron Company's

mine on the Eisenerz Mountain with the Eisenerz Railway. The several workings of the mine, of which the top one is 2,016 feet above the Railway Station, are connected by a series of self-acting inclines varying from 18 to 20 degrees in inclination to the horizon, and by a length of almost level line with the Railway Station at Eisenerz. The wagons which run on the level portion of the line weigh about $1\frac{1}{2}$ tons each when empty, and carry loads of $2\frac{1}{2}$ tons. The wagons are loaded at the top of the inclines, and are lowered one at a time in a horizontal position on platform wagons which run on the inclines only. The wagons are drawn by horses on the level portion of the line. The inclines are laid with iron rails weighing 27 lbs. to the yard. The speed of the wagons on an incline is regulated by a self-acting air-break, consisting of a three-armed fan with flat wooden blades connected with the main drum of the incline in such a way that the fan makes 128 revolutions to each revolution of the drum. The resistance offered by the air to the passage of the blades of the fan through it increases rapidly with any increase of speed, and thus the fan is able to absorb any excess of power in the descending wagon and to check undue acceleration of speed. In addition to the air-breaks there are lever-breaks on the drums. The ropes are of steel wire. The wagons travel on the inclines with an average speed of 4 miles an hour.—*Vide* Proceedings of Institute of C. E., Vol. 43, page 406.

From the foregoing examples of Rope Railways, all of which, though recently constructed, have been successfully worked, we learn that there is no practical difficulty in constructing or working Rope Railways of any form with inclines of 30 degrees of inclination to the horizon.

Second.—That if the loads to be raised are limited to one ton each they can be taken up a hill 3,000 feet high by a steel wire-rope in one stage.

Third.—That Steel wire-ropes will stand two years' continuous wear.

Fourth.—That accidents are, at all events, not more likely to occur on Rope Railways than on other railways. For experience has shown that, if proper break appliances are provided, trains can be stopped at once in the event of the ropes breaking, and the rope attachment itself is a safeguard against many classes of accidents to which trains with other systems are liable. This question will be more fully discussed hereafter.

Fifth.—That Rope Railways need not necessarily be straight.

Now, it is plain that both systems of Mountain Railways with ropes

can be worked with water; for water or turbine wheels can take the place of steam engines in the system worked by stationary engines, as is done on the Lausanne and Ouchy Railway, described at page 7, and water can take the place of any other load in the system worked by self-acting inclines. However, water or turbine wheels require a large supply of water, hence Rope Railways with stationary engines worked by water can, as a general rule, only be used in valleys, or on the lower slopes of hills, where an abundant supply of water can always be obtained, and the system of Rope Railways worked by self-acting inclines is, in its present stage of development, unsuited for lines where loads of variable weights have to be carried up as well as down, and traffic of all kinds has to be accommodated.

For Mountain Railways for general use in the hills in India a system is required which can be worked with a small expenditure of water, and can take loads of variable weights, of passengers or goods, uphill as well as downhill, and it is to supply this want that Sedgwick's Patent Hydraulic Lifts for hill stations have been designed.

Sedgwick's Patent Hydraulic Lifts for Hill Stations.—These Lifts are worked on the principle of the Rope Railway with self-acting inclines already described, but in place of carriages or wagons of the ordinary pattern being used, the carriages and wagons for these Lifts are each furnished with tanks (vide *Plate, Figs.* 1 and 2) capable of holding a large supply of water, and each tank is fitted with inlet and outlet pipes to enable it to be rapidly filled with water at stations, or emptied at any time.

The carriages are worked in pairs, each pair with its own rope, and the two carriages of each pair, when empty, are precisely alike in point of weight as well as in every other respect. A guard's compartment is attached to each carriage; from it the wheel and other breaks of the carriage can be worked, and in it are fixed the stop-cocks of the outlet pipes of the tanks and gauge glasses to show the depth of water in the tanks.

It is plain that in a Rope Railway with self-acting inclines the up and down carriages must always pass each other in the middle of the incline; hence if in the middle of the incline a short length of the line is laid double with points and crossings to enable the carriages to get past each other, the remainder of the line can be laid single. An arrangement of this sort has been adopted on the inclines of the Sao Paolo Railway, Brazil.—*Vide* Proceedings of the Institute of C. E., Vol. 30, page 29;

see also *Fig.* 4, page 13, which shows two passing places on a Lift with a single line of rails.

The endless rope of the Lift must be fixed so as to pass outside of both of the rails where the line is single, and outside both of the outside rails where the line is double, as shown in *Fig.* 4, page 13. The rope is passed round drums at the top and bottom of the incline, and supported on rollers in the usual way.

Water is laid on to the Lift by pipes from a tank or stream; it is not however absolutely necessary that the water should be laid on to the top station of the Lift; it will be shown afterwards that with these Lifts carriages can be run up to the top of an incline if a supply of water is available half way up the incline.

To work a Lift, a pair of carriages is placed upon the incline, and one carriage made fast at the top of the incline to the endless rope on one side, and the other carriage at the bottom of the incline to the endless rope on the other side. The maximum loads the Lift is capable of raising or lowering having been fixed, a load to be raised is put upon the carriage at the bottom of the incline, and if there is no water in the tanks of the carriage a sufficient quantity for working the Lift is run into them, and a signal then made to the station at the top of the incline. On the receipt of this signal the guard of the carriage at the top of the incline places any load which has to be lowered on his carriage, and then proceeds to run water into its tanks. When a sufficient weight of water, to counterbalance the weight of the load on the carriage at the bottom of the incline and to overcome the resistances of the rope and of the carriages has been run into the tanks of the carriage at the top of the incline, the carriage descends the incline by gravity, and drags the other carriage with its load up the incline. When the carriages reach the middle of the incline the pointsman at the double line turns one of the carriages through the siding and allows the other to run through on the main line, and thus the carriages pass each other. The tanks of the carriages must hold sufficient water to enable the Lift to be worked when there is a load to be raised and no load to be lowered. When there is a load to be lowered and none to be raised, it will be necessary, if the incline is a short one and the resistance of the rope therefore small, sometimes to weight the tanks of the carriage at the bottom of the incline with water. As soon as the carriages, respectively, reach the bottom and top of the incline

are made fast and unloaded, and are then ready to make another trip in the same way as before.

The speed of the carriages is regulated simply by running water out from the tanks of the carriages from time to time. To decrease the speed water is run out from the descending carriage by the guard, and to increase the speed water is run out from the ascending carriage by its guard: in this way the carriages can be stopped at any time without using the breaks, or if necessary they can be backed. And thus in a very simple and effective way the disturbing influences of acceleration, changes of gradient and curves, can be compensated for, and any speed which may be desirable can be attained and maintained under perfect control.

If an insulated copper wire is introduced into the hemp core of the steel-wire-rope of the Lift, and if Telegraphic Instruments and Batteries are provided for the carriages, the guards of the carriages will be able to signal by telegraph to each other directly at any time whether the carriages are running or standing. If the copper wire extended through one-half only of the line rope, the earth wires of the batteries would be connected with the wheels of the carriages, and the currents would pass to earth through the wheels and rails; but if the copper wire extended throughout the whole length of the rope, the circuit would be complete through the rope. The signals to be transmitted would be few, simple and easily learnt. As the carriages would be on a steep hill side, and the guards therefore visible to each other throughout the greater part of the run, they could signal if necessary to each other by flags or lights if aided by signalmen to transmit the signals at curves or gradient changing points.

To enable the carriages to be easily started at the commencement of a journey and to be brought up at the proper place at the end of a journey, the slope of the incline is made a little flat at the bottom station and a little steep at the top.

Trains of any size that may be required can be worked with these Lifts by putting a sufficient number of pairs of carriages, each pair with a separate rope upon the incline, and coupling all the ascending and all the descending carriages together.

To guard against accidents from the breaking of the rope a pair of plough anchors with counterpoises will be fixed in front of each carriage (vide *Plate, Figs.* 1 and 2) in such a way that when the drawing rope is tautened the anchors rise, and when the rope breaks or becomes slack

the anchors fall clear of the ends of the sleepers, and by ploughing up the ballast and the seat of the railroad gradually bring the carriage to a standstill, aided, if necessary, by the breaks of the carriage.

The carriages are provided with wheel-breaks of the ordinary form, and in addition, if required, with clip-breaks, to grip the top of the rail, as used on the Sera Do Mar inclines of the Sao Paolo Railway, Brazil, at the Botallack copper mines, Cornwall, and other railways, and already described at pages 6 and 7. These breaks have been proved repeatedly to be capable of stopping at once wagons on inclines of upwards of 30 degrees of inclination to the horizon, if the rope breaks.—*Vide* pages 74 and 76, Vol. 30, of the Proceedings of the Institute of C. E.

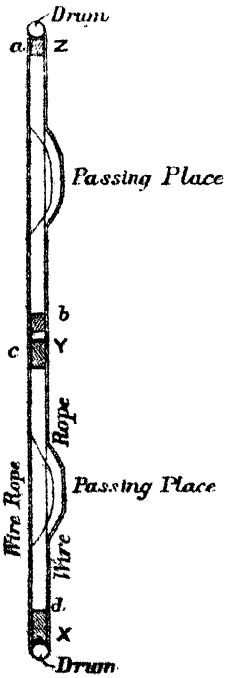
In addition to other breaks a powerful form of rope-break can be provided, consisting of a stout wire-rope, with its ends securely fastened at the top and bottom of the incline passed over rollers fixed to the side of the carriage; between the rollers on the carriage the rope passes clear over two stout blocks of soft wood fixed about six inches apart on the side of the carriage and under the short arm of a bent lever fixed on the side of the carriage just above the space between the two blocks of soft wood; by elevating the long arm of the lever by a screw in the guard's compartment the short arm is depressed, until it catches the wire-rope and forces it down upon the soft wood blocks; the motion of the carriage tends to jam the rope between the short arm of the lever and one of the blocks of soft wood, and the friction thus caused retards the carriage. This form of break can be used with vertical Lifts, or with Lifts with inclines of any degree of steepness, and by means of a draw-bar attached to the drawing rope and a spring, can be made self-acting if necessary.

On high hills and on hills where the slopes are not uniform the Lifts will be made in stages. With Lifts in stages the lines of the stages will run into one another, and the drums for the wire-rope at the top and bottom of the stages will be placed below rail level, so that a carriage after it has run over one stage may be detached from the rope of that stage and attached to the rope of the next stage, and in this way, when necessary, carriages may be run through from top to bottom of the Lift or *vice versâ* without being unloaded.

When a Mountain Railway has to be taken for a long distance across several ridges, the Loads, to be sent up or down, will be placed on light carriages built for running on a level line. On the inclines these car-

riages will be run on to Platform Wagons with Tanks (vide *Plate, Fig.* 1) as is done on the Eisenerz Railway, described at page 8. When the carriages reach the top or bottom of a ridge, they will be run off the Platform Wagon on to a length of level line and carried across the top of the ridge or across the valley at the bottom by attaching a tail rope to the ascending or descending carriage, as the case may be, of either of the adjacent Lifts, and again run on to a Platform Wagon at the next incline. In this way the delay and inconvenience of shifting from one carriage to another will be avoided. In cases where the Railway is carried for a considerable distance up valleys with easy gradients the rope can be worked as on the Lausanne and Ouchy Railway, described at page 7, by a Water-wheel or Turbine.

Fig. 4.



To show how carriages can be run up to the top of an incline, when a supply of water is available only at the middle of the incline.

Let X, Y, and Z (*Fig.* 4) be stations, respectively, at the bottom, middle, and top of an incline, having an endless rope passing round drums at X and Z.

And let *a* and *b* be two light carriages, of equal weights and without tanks, attached to opposite sides of the rope at Z and Y, respectively, and *c* and *d* be two heavy carriages of equal weights furnished with tanks and attached to opposite sides of the rope at Y and X, respectively.

And suppose that a supply of water is available at Y in the middle of the incline.

Then, if a load to be raised is put upon the carriage *d* at station X, and a load to be lowered on carriage *a* at station Z, and a sufficient weight of water run into the tanks of carriage *c* at station Y, it is plain that carriage *c* will descend the incline from station Y to X, dragging down carriage *a* with its load from Z to Y, and drawing carriage *d* with its load up from station X to station Y, and carriage *b* up from station Y to station Z. Then if *d's* load is shifted

to *a* and *a*'s load to *d*, and if water is run into *d*'s tanks, *d* with its load will descend to X, *b* will descend to Y, *c* will ascend to Y, and *a* with its load will ascend to Z.

a and *b* pass one another at the length of double line half way between Y and Z, and *c* and *d* pass one another half way between X and Y.

If a drum is placed below the rails at Y, *c* and *d* can have an additional rope if necessary. They must, however, still be attached to the rope connecting *a* and *b*.

When the incline of a Lift has more than 35 to 40 degrees of inclination to the horizon, or when the carriages have a tendency to jump off the rails, holding-down rails will be required. These will consist of lengths of angle-iron secured to the frame of the carriage in such a way that one side of the angle-iron will be in a plane parallel to the plane of the incline, and the other side in a vertical plane with its edge bearing against the underside of the rollers of the rope on each side; the rollers will have slotted bearings so as to allow for inequalities in the road. It is evident that the rope will not be retarded by the fact of the rails bearing against its rollers, for on the side on which the rope is fastened to the carriage the rope will be clear of the rollers opposite to the carriage, and on the other side where the rope will be on the rollers the rope and the rail will tend to turn the rollers in the same direction. Between the rope-rollers additional rollers for the rail can be fixed where necessary; and if necessary, continuous light angle-iron rails with one edge downwards, attached at intervals to bent supports, can be provided for the whole length of the incline; trucks or runners attached to the frames of the carriages so as to bear against the angle-iron rail will then keep the carriages from jumping off the rails of the incline. The shortening in the length of the Lift, which will be effected by using inclines requiring these holding-down rails, will pay for the cost of providing the rails.

The Plate shows the arrangement for a Lift with an incline of about 26 degrees 24 minutes, equivalent to a gradient of 1 in 2. With such a Lift the carriages for local traffic will be made in the form shown at *Plate, Fig.* 2, with which a series of tanks, each corresponding in length and width with the dimensions of the floor of a compartment of a carriage, are arranged in a series of steps up the frame of the carriage in such a way that when the carriages are on the incline the tops of the tanks are in horizontal planes. The tops of the tanks form the floors of the com-

partments of the carriages. The frame of the carriage is formed of two half-girders (*i. e.*, girders with flanges at one side only of the web) riveted to the tanks on either side. When the Lifts are working in connection with railways in the plains for through traffic, the wagons can be made in the form shown at *Plate, Fig.* 1, in which the top of the tank of the wagon forms a platform on which railway carriages of the ordinary form can be run, and thus sent up the Lift in a horizontal position without being unloaded in the same way as is now done at the self-acting inclines of the iron mines at Eisenerz, already described. This form can also be used for open wagons for local traffic.

For rough Lifts such as are required by the Forest Department for timber hoists or runs, or by Planters for raising produce or labour from their gardens up to the factories, or for rough roads for general purposes, the wagons or trucks, excepting the wheels and breaks, can be made altogether of timber in the roughest possible way, in the form shown at *Plate, Fig.* 1 (omitting the Guard's compartment), the seams of the planking of the tanks being caulked with oakum. With these rough trucks the tanks would be provided with short lengths of leather hose in place of inlet and outlet pipes with stop-cocks. It is evident that if the length of the leather hose is greater than the depth of the tank, so long as the end of the hose is kept up the water will remain in the tank, but as soon as the end of the hose is let down the water will begin to run out. In addition to the self-acting anchor-break a rough form of scotch-break worked by a lever arm from the top can be provided for the wheels.

For rough Lifts the rails can be formed of wooden planks on edge. The planks can be bound with iron if the traffic is heavy. This form of railroad is said to have been used in America, and has been lately used with complete success by the Forest Department in tramways at the Jounsar Forest.—*See* a Paper on Sleeper Slides in the Jounsar Forests, page 262, Vol. III., Roorkee Professional Papers on Indian Engineering, [Second Series.]

The calculations for these Lifts have been based on those for self-acting inclined planes in Rankine's Civil Engineering, page 636.

If T = the weight of an empty carriage.

W = the weight of the load to be put on the descending carriage in order that the tractive force of the carriage may just balance the resistances of the Lift.

W_1 = the maximum load for the ascending carriage.

R = the weight of the rope and of the pullies which support it.

f = the co-efficient of friction for the carriages.

α = the angle of inclination of the incline to the horizon.

Then, according to Rankine, the resistance of the rope may be assumed to be $\frac{R}{20}$, and since the carriages are worked in pairs, and the carriages of each pair are of equal weights when empty.

∴ the frictional resistance of a pair of carriages $= f(T + W + T + W_1)$.

Now, in order that the descending carriage may be sufficiently weighted to counterbalance the weight of the ascending carriage with its load, and to balance the Resistances to motion arising from the friction of the Rope and of the pair of carriages.

$(T + W) \sin \alpha$ must be $= (T + W_1) \sin \alpha + \frac{R}{20} + f(T + W + T + W_1)$

$$\text{whence } W = \frac{W_1 \sin \alpha + \frac{R}{20} + f(2T + W_1)}{\sin \alpha - f}$$

∴ the Lift will work if the load on the descending carriage exceeds the value obtained for W by the solution of the above equation.

The greatest ordinary working strain on the rope must clearly

$$= \left(T + W + \frac{\text{Weight of Rope}}{2}\right) \sin \alpha.$$

If T = 3 tons, or 6,720 lbs.

$W_1 = 1\frac{1}{4}$ tons, or 2,800 lbs.

$\alpha = 30°$.

$f = \cdot 004$.

Also if the rise of the Lift or the difference of level between the top and bottom stations = 3,000 feet.

And if a steel-wire-rope $3\frac{1}{2}$ inches in circumference, supported on pullies, at intervals of 7 yards, weighing 25 lbs. each, be used.

Then the length of the incline will = 3,000 cosec 30°.

= 6,000 feet.

∴ the incline will require an endless rope about 12,080 feet long.

Now the weight of $3\frac{1}{2}$-inch steel wire rope, according to Molesworth's Pocket-book is $1\frac{2}{3}$ lbs. to the foot.

∴ the rope will weigh $12{,}080 \times 1\frac{2}{3} = 20{,}134$ lbs.

Also the rope will require $\frac{12080}{21}$ pullies to support it.

$\therefore$ the weight of the pullies will be $\frac{12080}{21} \times 25 = 14{,}381$ lbs.

$\therefore$ R $= 20134 + 14381 = 34{,}515$ lbs.

Then substituting in the equation

$$W = \frac{W_1 \sin \alpha + \frac{R}{20} + f(2T + W_1)}{\sin \alpha - f}$$

the value for R thus obtained, and the values for T, W_1, α and f, given above, we get W $= 6{,}433$ lbs. And as the Lift will work as soon as the load on the descending carriage exceeds W.

$\therefore$ $2\frac{7}{8}$ tons or 6,440 lbs. will be a sufficient load for the descending carriage.

The greatest working tension on the rope, using the formula given above, will therefore be

$$= \left(6720 + 6440 + \frac{20134}{2}\right) \sin 30° = 11{,}613 \text{ lbs.}$$

But, according to Molesworth's Pocket-book, the safe working load for $3\frac{1}{2}$-inch steel wire rope is 12,096 lbs.

Supposing that no load at all is put upon the ascending carriage then will $W_1 = 0$.

And substituting the other values as before, we get

W $= 3{,}588$ lbs. = Load on the descending carriage to balance friction.

Again, if the rise of the Lift is only 1,000 feet, and if $W_1 = 2\frac{1}{8}$ tons. Whilst T, f and α have the same values as before.

And if a steel wire rope $3\frac{1}{4}$ inches in circumference, weighing $1\frac{1}{3}$ lbs. to the foot, and supported as before, be used,

Then will the length of the rope $= 4{,}080$ feet.

And its weight $= 4080 \times 1\frac{1}{3} = 5{,}440$ lbs.

Also the weight of the Pullies $= \frac{4080}{21} \times 25 = 4{,}857$ lbs.

$\therefore$ R $= 5440 + 4857 = 10297$.

And substituting as before we shall get W $= 5{,}938$ lbs.

$\therefore$ the Lift will work if the load on the descending carriage $= 2\frac{3}{4}$ tons, or 6,160 lbs.

And the greatest working strain on the rope will then be

$$= \left(6720 + 6160 + \frac{5440}{2}\right) \sin 30° = 7{,}800 \text{ lbs.}$$

But the safe working load for 3½-inch steel wire rope is 8,736 lbs.

If $W_1 = 0$,

then will $W = 1{,}146$ lbs.

We are now in a position to ascertain approximately what the consumption of water in working the Lifts would be. It has been already shown at page 11 that in working a Lift water is run out from the tanks of the ascending carriage when it is necessary to accelerate the speed, and from the tanks of the descending carriage when it is necessary to reduce the speed. It follows therefore that at starting a certain quantity of water must always be kept in the tanks of both carriages.

Let it be assumed that ¼ of a ton on the ascending and ½ a ton on the descending carriage are sufficient weights of water for the two carriages for working a Lift with a rise of 3,000 feet, and that ⅛th of a ton on the ascending and ¼ of a ton on the descending carriage are sufficient weights when the rise of the Lift is 1,000 feet only.

And let it be assumed that the other conditions are the same as assumed in the calculations.

Now, it has been shown that on a Lift with a rise of 3,000 feet a load of 2⅞ tons, on the descending carriage, is just able to overcome the resistances of the Lift when there is a load of 1¼ tons on the ascending carriage; but in order that the carriages may travel with sufficient speed over the Lift ¼ of a ton additional load must be given to the descending carriage so that the total load required for the descending carriage will be 3⅛ tons.

Hence if there are full loads of goods for despatch at both stations of the Lift the guards would put a load of 1 ton of goods and ¼ ton of water on the ascending carriage and a load of about 2⅝ tons of goods and ½ ton of water on the descending carriage, and thus a paying load of one ton would be raised with an expenditure of ½ a ton of water at the top station.

When there is a full load to be sent up and nothing to be sent down, it is plain that the expenditure of water at the top station in raising a paying load of one ton will be 3⅛ tons. When there is a full load to be sent down and nothing to be sent up a load of 1¼ tons of water would be placed on the ascending carriage, (of which one ton would be left in the tanks of the carriage when it reached the top station and would be available afterwards for the descending carriages,) and a load of 2⅝ tons of goods and ½ a ton of water on the descending carriage.

Similarly with a Lift with a rise of 1,000 feet it will be seen that a load of $2\frac{7}{8}$ tons on the descending carriage will lift a load of $2\frac{1}{8}$ tons on the ascending carriage and that a consumption of $\frac{1}{4}$ of a ton of water at the top station will raise a paying load of 2 tons when there are full loads of goods for both the ascending and descending carriages. Also that when there is a full load to be sent up and no load to be sent down the expenditure of water at the top station will be $2\frac{7}{8}$ tons to lift a paying load of 2 tons.

Hence supposing that 12 tons each way is the average daily traffic with an ordinary Hill Station, we shall be safe in assuming that this can be carried by an expenditure of 35 tons of water at the top station. Thirty-five tons of water per day represents 4,00,000 cubic feet per year, a quantity which could be supplied by a tank 150′ × 100′ × 15′ deep, holding about six months' supply.

It will be neither necessary nor practicable to load the carriages with great nicety, any slight excess or deficiency of load in either of the carriages can be compensated for by running water out from one of the carriages.

As on a Lift in stages the water from the tanks of the descending carriages of the top stage will be available for working the next stage, and so on down the Lift (though a small quantity of water will have to be added at each station on the way down to make up for the quantity expended during descent in working the Lift) hence, so long as the inclines rise uniformly and the stages are all of the same length, the expenditure of water will vary with the length of the stages, but will be independent of the total height of the Lift.

It is plain that whenever it is necessary to economize water the Lifts should be made in short stages. However, at places where the supply of water is liable to run very short, some part of the tanks of the carriages can be made to open at the side so as to enable the carriages to be partly weighted, when necessary, with stone or rubbish from the hillside, at such times only sufficient water to work the Lifts would be used, and the remainder of the load required to counterbalance the load on the ascending carriage and the resistances of the Lift would be made up with stone, &c., and in this way, if necessary, the Lifts could be made to bring up from below all the water they actually required. The importance of the plan of working carriages to the top of an incline by a water-supply available half

way up the incline, described at *Fig.* 4, page 13, is now apparent, for it not only enables water draining off from the immediate sites of hill stations, and therefore unfit for drinking purposes, to be used, thus enabling the Lifts to get a supply without interfering with the water-supply of the station, but in view of the fact that the stages of Lifts can be made 3,000 feet high; it also will enable the Lifts to be worked at places where the rainfall is scanty, by water obtained from reservoirs or springs situated, if the side of the hill has a slope of 30 degrees, more than half a mile down the hillside, and thus having a very wide extent of feeding ground.

The existence high up in the hills of the natural Lakes of Tsho Morari in Cashmere Territory (some 14,000 feet above sea level), of Kundalu on the ridge above Belaspur, and many others, and of the artificial Lakes at Nainee Tal, on the top of Mount Aboo, and elsewhere, proves that little difficulty would be found in constructing even large tanks in suitable sites near the tops of ridges. And few who have studied the conformation of hills in India carefully can have failed to notice the splendid sites for Reservoirs everywhere available. The Happy Valley at Mussoorie and Beechwood at Darjeeling are instances familiar to many.

It is claimed for these Lifts that they are cheaper, safer, and quicker than any other form of Mountain Railway, and that they can be more readily adapted than any other system to suit the exigencies of all situations.

With regard to cheapness. There is no expensive machinery about these Lifts. They can be worked with a single line of rails of a very light pattern; and if the wire-rope, the rails, and the wheels are obtained from England, the carriages, and all the other parts of the Lifts, can be constructed in any of the large workshops in India. Also the Lifts can be taken straight up a hillside of any degree of steepness, or, if necessary, up the face of a precipice, by using a vertical run and modifying the form of the carriages. Indeed, as a rule, the steeper the incline the more cheaply can the Lifts be constructed and worked, and as the ordinary slopes of the sides of the higher hills in India vary from about 1 in $2\frac{1}{2}$ to 1 in $\frac{1}{2}$, in this way by enabling very short lines to be used, Rope Railways have a great advantage over railways worked by locomotives on the Rigi and on the Fell systems, which are limited, respectively, to maximum gradients of 1 in 4 and 1 in 11. Further, the Lifts do not necessarily require

a supply of water at all at the top station, for they can be worked, *vide Fig.* 4, page 13, if a supply of water is available at a considerable distance down on a hillside. This, taken in connection with the fact that they can be worked on any slope, will allow a wide choice of sites to be made in applying them to any particular situation, and will enable the Lifts to be located generally in positions where a supply of water from a stream or spring is close at hand. Large, however, as the saving with these Lifts will be in construction, the saving in working expenses will be still larger, for they require no skilled labour to work them; they can be easily repaired, and the motive power will generally cost absolutely almost nothing. The renewal of the wire-rope will be the most expensive item connected with the working of the Lifts, but it has been found (*vide* page 270, Vol. 41, Proceedings of Institute of C. E.) at the Pribram mine, where 112,000 tons appear to be raised every year from a depth of 3,673 feet on a cradle carrying a load of 1 ton, and making 20 trips per hour for 16 working hours every day, with a steel wire-rope weighing 1 ton 15 cwts., that steel wire-ropes last two years with continous wear. If the cost of steel wire-rope is taken at £120 per ton, it follows that a charge of one-third of a penny, on each ton raised to a height of one mile, will cover the cost of providing wire-ropes.

With regard to safety. Every one who has had any experience of hill roads in India during the rains must be aware that hill roads are liable to be rendered impassable after heavy rain by the destruction of bridges, by landslips, or by trees, or by masses of rock which roll down from above, mainly because, in order to get suitable gradients, these roads have to wind round the hillsides, and thus interfere with the drainage and with the stability of the soil of the hillsides. Therefore with Mountain Railways, which from their nature are more easily blocked than ordinary roads, and which in India are required to work throughout the rains, it is a point of great importance that the railroads should be carried as straight as possible up the hillsides, so as to avoid as much as possible disturbing the hillsides. Now, from what has been already said, it is plain that Rope Railways alone, of all systems of Mountain Railways, can be carried straight up a hillside, and that railways worked by locomotives must necessarily, more or less, wind round the hillside, and therefore be in a less secure position with regard to obstructions from landslips, &c., than Rope Railways. Further, though Rope Railways are liable to accidents from the breaking

of the rope, they are less liable to such accidents than are railways worked by locomotives to accidents from the breaking down of the machinery, and it is even easier, if a rope breaks, to stop a train on a Rope Railway than it is to stop a train on a railway worked by locomotives, if its machinery break down, because with a Rope Railway self-acting breaks can be used, which will commence to retard the train directly the rope breaks, but with locomotives everything must depend upon the vigilance of the driver, supposing that an accident to the machinery occurs whilst a train is descending. With regard to other classes of accidents to which Mountain Railways, which work during the rains, must be exposed, though the jaws on the Rigi locomotive and the horizontal wheels on Fell's system may prevent derailment under ordinary circumstances, they would be of no use in the event of a bridge, or of a portion of the road, giving way suddenly or of a landslip, or of a falling rock or tree catching the train, or even if an axle or a tire were to break; in such case the destruction of the train with a locomotive would be almost inevitable, because on the steep hillsides in India such a train once over the side could hardly be saved; but with a Rope Railway in such case, so long as the rope attachment held, no great amount of harm would be likely to happen to the train; and as the rope always remains taut there is no reason why the rope attachment should give way in an accident of this sort. The Rigi system may do very well on steep hillsides for railways constructed, as the Rigi and several other railways have been, to accommodate tourists, and worked for six or seven months in the year during fine weather, when the line can be constantly patrolled, and a look-out kept in front of each train to see that the rack is clear of small stones or other obstructions (*vide* Vol. 36, pages 115 and 116, Proceedings of Institute of C. E.), and a line with gradients of 1 in 10 can be doubtless worked with safety for all descriptions of traffic on compartively flat slopes; but such a system could not be worked with safety during the rains on the steep hillsides in India, when dense mists and drizzling rain would day after day render a proper look-out impossible, and when a train may at any time be caught in a heavy shower, which will send stones and timber down upon the railroad from above. A few moments' consideration will convince any one that Rope Railways alone can be safely used for the hills in India during the rains.

With regard to speed. The speed attained on the Rigi Railway of 3 or 4 miles an hour on a gradient of 1 in 4, or on the Fell system of 10

or 12 miles an hour on a gradient of 1 in 12, is small compared with that attained on Rope Railways; for instance, on the Pittsburg Railway in America, where the carriages travel at the rate of 9 miles an hour on a gradient of 1 in 1·72 (page 275, Vol. 41, Proceedings of Institute of C.E.)

On railways worked by locomotives as well as on railways worked by stationary engines, increased speed cannot be attained without considerably increasing the working expenses, but with these Lifts any speed that can be desired can be obtained by merely adding a few more pounds of water to the tanks of the descending carriage, or running off a few pounds from the tanks of the ascending carriage without ordinarily causing any addition to the working expenses. Also the speed is under the control of the guards of the carriages, who can see the state of the road ahead of them. The plough-break described at page 11 will undoubtedly, under one of its forms, whether as a self-acting anchor in front or as plough-share lowered by the guard behind, enable a higher speed to be attained on inclines than has hitherto been practicable.

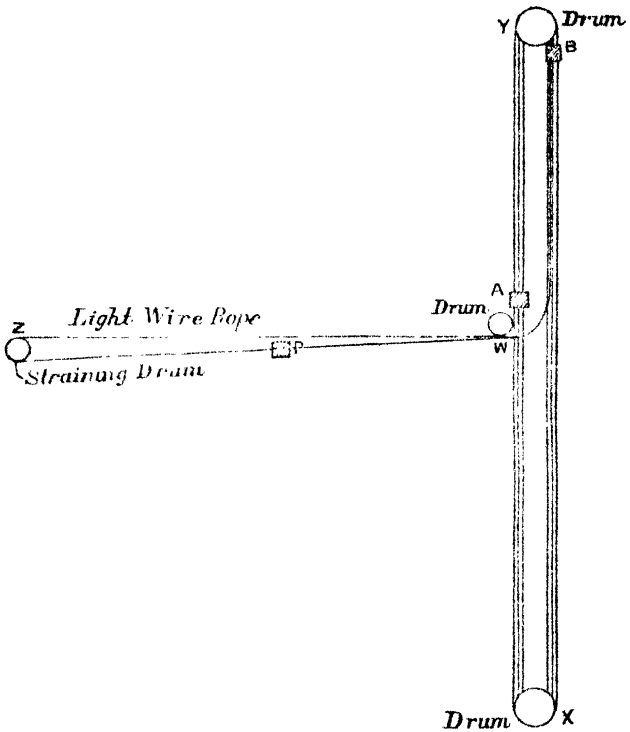
As speed to some extent determines the carrying power of a railway, it is a question of considerable importance.

With regard to the question of general usefulness. We have in India on the higher hills water power, almost everywhere in abundance, available, not only to provide cheap means of transport, but also available at almost a nominal cost to work machinery of every description. If properly applied, water power can be used to make cloth, to work machinery for manufacturing tea, to saw timber, to plough land, to harrow, to sow, to reap, to cart away produce, to thresh, or to grind, &c., &c.

To use water power for agricultural operations, we have only to take a Lift with a double line of rails and with drums at X and Y, the bottom and top stations, respectively, of the Lift, and with a pair of wagons A and B working in the usual way on the Lift. Then if A is attached at such a point on the endless rope of the Lift as will make the distance travelled by A and B equal to the length of the field to be ploughed, or reaped, &c., and if a length of light wire-rope with rollers is then taken and its ends made fast to the wagons A and B on the Lift, and the loop of the light wire-rope strained by a straining drum at Z, fixed at the far end of the field to be ploughed, and guided by a drum at W, it is plain that a plough or a reaping machine P attached to the light wire-rope

will be drawn across the field towards Z, when wagon B descends and

Fig. 5.



wagon A ascends the incline of the Lift, and will be drawn back again across the field when A descends and B ascends.

The distance travelled by P plainly depends on the distance A is fixed below the top station Y of the Lift. By moving the straining drum at Z and the rollers supporting the light wire-rope either up or down, as may be necessary, a field of any width can thus be cultivated in any direction, an additional guiding drum being provided whenever it is necessary to plough up and down instead of across the hillside. If the Lift have an incline of 30 degrees and the wagons move at a speed of five miles an hour, the Lift will do the work of a steam engine of 18 H.-P. if able to

raise loads of one ton, or of an engine of 54 H.-P. if able to raise loads of three tons. One Lift if favourably situated will thus be able to cultivate all ground within a distance of from one half to one mile above, below, or on either side of it. By attaching a cart to the light wire-rope and adjusting the travel of the wagons on the Lift, produce can be carted in from the fields to the Lift, and sent up by the Lift to the farm-yard or factory. If the loop of the light wire-rope is passed round the shaft of a threshing, sawing, tea-making or other machine, the Lift can be used to drive any description of stationary machinery with the light wire-rope as a belt. After the wagons on the Lift have made one run the rope will move in the reverse direction, and it is therefore necessary to put an additional cog-wheel into gearing in the machinery for the second run, and to put it again out of gearing for the third run, and so on; and thus with a rough Lift, with a timber railroad and timber wagons as described at page 15, a farmer would be able to cultivate his fields, cart in the produce, and thresh, and, if necessary, grind his corn; the tea planter would be able to do a considerable part of the work connected with tea manufacture, and the forest officer would be able to get timber out of any forest, and cut it up, if necessary, before sending it away.

It is not of course imagined that the method here advocated of utilizing water power to drive machinery is the most advantageous way of employing water power for the purpose when a large supply of water and when trained mechanics for erecting and working machinery are available, and workshops able to execute the necessary repairs are close at hand. This method though a rough one has these advantages, viz., it enables a very small supply of water to be turned to account, and is so simple in construction that any one with common sense will be able to understand how to put it together and work it; further any good mistry will be able to repair it when necessary. These are advantages which render it peculiarly fitted for employment in the hills.

If we would only avail ourselves of the water power often available on the hills at our very doors, work could nowhere be done so cheaply as in the hills, and no form of transport could compete in cheapness with transport in the hills. All that is wanted is some one to show practically how cheap, how effective, and how safe is the grand power we are neglecting. The subject is surely one worthy of the attention of Government. The climate of the hills in India is as good as any other climate in the world,

and Englishmen do not degenerate physically in it, neither would they, in all probability, degenerate morally if large colonies of Englishmen were formed; also there is good reason to believe that land could be cultivated by the aid of water power more profitably in India than it can be cultivated by manual labour in any of our colonies. If we had a few hundreds of thousands of English or Eurasian planters and farmers in the hills, with a fair proportion of them enrolled in a militia reserve, available at time of need for service anywhere in India, we should be able to reduce the strength of our army in India by one half. In view of the great expense of keeping up an army in India, an expense which must be ever increasing, it would pay well to give free grants of land and assistance in loans, under proper supervision, of machinery for cultivation to English settlers on condition of joining the militia. The nucleus of a force of militia could be obtained by encouraging time-expired men from the army to settle, and if it could be shown that land could be profitably cultivated in the hills, there would be no lack of settlers.

The Swiss by recently constructing a Railway worked by water power between Lausanne and Ouchy, described at page 7, have set us an example which we should do well to follow.

It is perhaps necessary to point out that the objections usually brought against Rope Railways with Stationary Engines, viz., that they are only suited for short lines, because on a long line the failure of one engine would stop traffic on the whole line, that they can only be used economically where straight lines can be obtained, because sharp curves are inadmissable with them, and that they are consequently unsuited for general application, do not apply to Lifts worked on the principle of the Hydraulic Lifts.

To show this, it must be premised that with the Hydraulic Lifts, the cost of construction is not increased by increasing within reason, on a given length, the number of Changing Stations; because, though the amount of rolling stock and the number of drums for the top and bottom of inclines will be increased, the weight of the rope and the quantity of water required for working the Lift will be largely diminished, *vide* calculations pages 15, 16, 17 and 18.

Also an increase on a given length to the number of Changing Stations in no way increases the chance of break downs occurring with the Hydraulic Lifts.

With a Rope Railway with Stationary Engines, however, an increase

to the number of Changing Stations will, by increasing the number of Stationary Engines required, add very largely to the cost of construction and greatly increase the chance of break downs occurring.

This being admitted, if now the loads sent up or down the Hydraulic Lifts are placed, as is done on the Eisenerz Railway, described at pages 7 and 8, on wagons which are built to run on level lines only, and are sent up or down the inclines in a horizontal position on platform wagons built to run on inclines only (vide *Plate, Fig* 1); also if wherever the line requires to make a bend a Changing Station is introduced and a turn-table put in, in a horizontal position, at or rather under the point where the direction of the line is changed; and if the turn-table is connected with the top of the first incline and the bottom of the next incline by a very short piece of level straight line passing under the drum at the top of the first and over the drum at the foot of the next incline; also if when a loaded carriage has reached the top of the first incline it is run, by means of a ramp (the platform wagon being now up a little high for the purpose), off the rails of the platform wagon, down on to the rails of the piece of level straight line at the head of the incline, and by this straight line, hand-shunted, or hauled, by a tail rope from an ascending or descending carriage of one of the adjoining Lifts, on to the turn-table and shifted by the turn-table on to the piece of level straight line leading to the next incline and thence run on to the platform wagon at the foot of the next incline, and thus sent up the Lift. Then it will be possible to construct in this way a line worked by Hydraulic Lifts with more bends in it than could be introduced into a line laid out with curves on any system worked by locomotives, without at the same time reducing the speed relatively below that with other systems.

For example, take the case of a station, 5,000 feet above the plains. A Rope Railway will run up to a height of 5,000 feet in a length of two miles, or under, at an average speed while running of not less than six miles an hour. Supposing that five Changing Stations are introduced, thus dividing the line into six different inclines, which may be zig-zags if necessary, and supposing that each Changing Station involves a detention of seven minutes, (as the turn-table can be quite close to the top and bottom of the inclines, this amount of detention should be more than sufficient,) then the ascent would be made with the Hydraulic Lifts in fifty-five minutes.

A Railway on the Rigi System cannot ascend to a height of 5,000 feet in a shorter run than four miles, and its speed on an incline of 1 in 4 is three miles an hour. Hence the ascent with a railway on the Rigi System would occupy one hour and twenty minutes.

This disposes of the objection that straight lines are required for these Lifts, and with regard to liability to break-downs, it has been already shown that break-downs are even less likely to occur with Hydraulic Lifts, from the breaking of the Rope than they are with a Railway worked by Locomotives from the breaking down of the machinery of the Locomotives. And if with the Hydraulic Lifts, a spare Rope on separate pullies is provided for each incline, the breaking of a rope would cause less detention than would the breaking down of a Locomotive, on other systems.

W. S.

No. CCLXIX.

THE COMPLEMENT OF ROLLING STOCK REQUIRED FOR A SYSTEM OF RAILWAYS.

By Capt. H. Wilberforce Clarke, R.E., *Offg. Depy. Consulting Engr. for Guaranteed Railways.*

1. Paragraph 2 of letter No. 3803-10R. of 19th October, 1877, addressed to—

the Governments of Madras and Bombay,
the Consulting Engineers to the Government of India for Guaranteed Railways,
the Directors of State Railways,
the Secretary of State, for information and communication to the Boards of Directors of the Guaranteed Railways,

runs as follows :—

"The difficulty of ascertaining the *complement of stock for a line is great;* but the ton-mileage required to be done affords the means of approximating to it. If it could be so arranged that wagon for wagon be exchanged at junctions, the relation between the stock of each line and the work required of it would readily be seen.

"The possibility of hiring to, or the necessity of hiring from, a neighbour would be realised, and the expediency of permanently increasing or decreasing the stock would be forced upon attention."

And the order attached directs—

"that the freest discussion with the Railway Officers be invited, and their opinions communicated at a very early date."

From the above extract, and the circulation which has been given to it, it is manifest that the Government of India attaches great importance to the subject, and considers that a solution of the difficulty has yet to be discovered. In this paper a method,—by which the *complement of stock* required for a line, or system of railways, can surely and easily be found,—is investigated.

2. On a new line of railway, the rolling-stock is determined by the experience gained on railways in the neighbourhood; the number of vehicles is more or less arbitrarily decided.

But when the line is in *working order*, and *distressed by want of rolling-stock* to meet the traffic which pours into it, the data (as will be shown in this paper) are at hand for determining the complement of rolling-stock necessary for its full working.

In order to obtain the *limit of work* which can be got out of a vehicle under the particular circumstances of the traffic of the time, it is necessary that the line should be working at its extreme limit of carrying power.

It is unnecessary to consider the delays, or the running of empty wagons: they are the accidents of circumstance, or features of the traffic; they are contingencies that will happen for a short, long, or continuous period, according to the nature of the traffic, and the degree of skill with which it is worked, and provision must be made for them.

3. The full power of the rolling-stock of any railway, under the circumstances of traffic, would be obtained when each vehicle ran continually throughout the day, during the period of time under consideration, with its average freight, at "between-station-goods-speed" (s miles) per hour.*

In such a case the goods vehicle-mileage would be—

= number of goods vehicles *constructed* × 24 hrs. × s miles × period of time in days.

And the difference between this goods vehicle-mileage and the *actual* goods vehicle-mileage (paying and free) given in Table G-11 of the Review of the Revenue Account gives the detention during the time under consideration (reckoned in goods vehicle-mileage) due to all causes.† The ton-mileage given in the Revenue Accounts is not the ton-mileage effected in any period for which the accounts are rendered (say half a year), but in a period:—

(t) = (period under consideration T — detention).

During this period t, all the goods vehicles have been running through-

* It is as legitimate for the Railway Administrator to make use of this *imaginary vehicle-mileage*, as it is for the Astronomer to use, in his calculations, an *imaginary sun*, whose motion in right ascension is strictly uniform, and whose days are exactly the mean of all the solar days during the year.

† That is, detention due to repairing, shunting, loading, unloading and stopping at stations.

out the day of 24 hours, with their average freight, at "between-station-goods-speed" (s miles) per hour.

4. Let N = total number of goods vehicles constructed (including those under repairs) on any railway during the time T under consideration.

n_1 = " " home goods vehicles on foreign railways,

n_2 = " " foreign goods vehicles on the home railway,

m_1 = time in months during which the home vehicles were absent,

m_2 = " " " foreign vehicles were on the home railway,

T = time in months under consideration.

Then for the time T the *available stock* is—

$$= \left\{ (N - n_1) + n_1 \times \frac{T - m_1}{T} + n_2 \times \frac{m_2}{T} \right\} = S \text{ (say)}.$$

Let V = goods vehicle-mileage of home and foreign vehicles (available), which might have been run had the home and foreign goods vehicles been employed continually during the day, in the period of time T considered, at the "between-station-goods-speed" (s miles) per hour—

$$= S \times \tfrac{\text{hrs.}}{24} \times s \times T.$$

v = goods vehicle-mileage (paying and free) of home and foreign vehicles (available) actually run on the home railway, taken from Table G-11 of the Review of the Revenue Account (or adapted from that Table) or the audited weekly returns for the time T under consideration.

D_v = detention, reckoned in goods vehicle-mileage, in the time T—

$$= (V - v).$$

D_d = detention, reckoned in days, per wagon, in the time T—

$$= \frac{D_v}{S \times \frac{\text{hrs.}}{24} \times s} = \frac{V - v}{S \times \frac{\text{hrs.}}{24} \times s}.$$

t = actual working days or *effective time*, in the period T under consideration—*

$$= (T - D_d).$$

w = freight in tons per wagon, taken from Table A_8 or G-1, or M-1 of the Review of the Revenue Account.

W = weight in tons of a wagon and its freight.

F = additional gross ton-mileage, which is desired.

Then the gross work done by one wagon is—

$$= W \times \tfrac{\text{hrs.}}{24} \times t \times s \text{ ton miles.}$$

* By *working days* are meant days during which *all* the goods vehicles, those constructed and those hired, travel continually through the day at "between-station-goods-speed" per hour.

It may be well to remark that all the data sent as gross goods ton-mileage, goods vehicle-mileage (paying and free), &c.,—whether taken from the

(*a*), audited weekly returns,

(*b*), or from the half-yearly Revenue Accounts, must be adapted to the time T under consideration.

It may be shown that :—

$$t = \frac{\text{vehicle mileage (Table G-11 of the Review of the Revenue Account)}}{\text{number of vehicles (Table 12 of the Revenue Account)} \times \text{hours in a day} \times \text{speed between stations}}$$

And the number of wagons required to do the gross ton-mileage F is—

$$= \frac{F}{W \times \frac{\text{hrs.}}{24} \times t \times s}$$

a formula which commends itself by its extreme simplicity.

5. At any time the work done on a railway is *represented* by the ton-mileage; but the ton-mileage is *not* the *measure of work done*. The *instrument* by which the *work* has been done is the *rolling-stock*, and must be considered.

To compare the *work done*—

(*a*), at different periods on the same railway,

(*b*), on one railway with that on another, whether of the same, or of different gauge, the ratio of $\frac{\text{freight ton capacity of goods stock}}{\text{gross goods ton-mileage}} = \frac{1}{R}$ must be used as the *measure of work done*.*

6. On account of obstacles presented by the *direction* in which the traffic flows, it will sometimes occur that a large amount of rolling-stock is required to obtain the *work* R which at other times is effected with a small amount of stock. It is the first aspect of the traffic which has to be considered, if the number of vehicles for the *maximum traffic*, at any particular period, is required to be known.†

The period during which the rolling-stock is most severely tried (in a *traffic sense*) has now to be determined.

(*a*). When traffic flows from both ends of the line, R will be large, and v will be small, or the ratio $\frac{v}{R}$ will be a minimum.

(*b*). When the traffic flows from one end of the line in order that the *same* work R may be done, v will be large; hence the ratio $\frac{v}{R}$ will be a maximum.

*Let $\frac{1}{R_1}$ = measure of work done on another Railway B.

f = vehicle mileage (Table G—II of the Review of the Revenue Account) on Railway A. / number of vehicles (Table 12 of the Revenue Account) × days in the time considered

f_1 = ditto, ditto, ditto, on Railway B.

Then $\frac{f}{f_1} = \frac{R}{R_1}$

† The expression "maximum" traffic requires to be defined. It means the maximum traffic at a certain period only, under the *existing* circumstances of the railway.

If its mileage (single or double), its gauge, its stations per mile, its gradients, &c., be altered, the maximum traffic of the railway will alter too; and a fresh departure, from fresh data, should be taken.

The means of traffic being supplied, the traffic in some cases multiplies and (as it were) reproduces itself

This fact does not vitiate the value of the formula which can *easily* be re-applied, as circumstances demand. Indeed by means of the formula evolved in this Note, the rolling-stock may constantly be kept in balance with the traffic, and *waste* be avoided.

(*e*). When the traffic is languid, the work R is necessarily small, while v does not diminish in the same proportion; hence the ratio $\frac{v}{R}$ will be neither a minimum, nor a maximum.*

Hence the period during which the traffic is *truly* the most severe, or the strain on the rolling-stock *truly* greatest, is when—

$$\frac{v}{R} \text{ is a maximum.}$$

For the Eastern Bengal Railway, the value of $\frac{v}{R}$ is given for each—

half-year, December 1870 to June 1877, *see* Tables (II.)
month, November 1876 to October 1877, *see* Table (VI.)

7. By means of the three formulæ—

(*a*), number of wagons required for certain *work* $= \frac{F}{W \times t \times s \times 24 \text{ hrs.}}$ paragraph 4),

(*b*), measure of work done $= \frac{\text{ton capacity of rolling-stock}}{\text{gross-goods-ton-mileage}} = \frac{1}{R}$ (paragraph 5),

(*c*), intensity of the work done $= \frac{\text{energy with the stock has been used}}{R} = \frac{v}{R}$ (paragraph 6),

the rolling-stock can easily be adjusted with the greatest nicety to the traffic.

It may be asserted that these three formulæ provide for *all* the circumstances of traffic, whether—

(*g*), it flows from one end, or from both ends of the line;
(*h*), home wagons are lent to foreign lines, or not;
(*i*), foreign wagons are running through on the home line, or not;
(*j*), foreign wagons are borrowed, or not;
(*k*), the wagons be of the same capacity, or not.

Any question, relating to traffic, can, with exactitude and ease, be determined by the aid of these three formulæ.

8. It would be of the greatest utility if the three formulæ (mentioned in paragraph 7) were worked out for every railway in India, Guaranteed or State: a true comparison of the *real work* done by each railway could then be made.

9. Difficulty was found in framing Table (VI.)

In the audited weekly returns, Eastern Bengal Railway,—

(*n*), for the 10 months, November 1876 to August 1877, the ton-mileage was *not* given; for September and October 1877, it was given;

* The vehicles will run light: their number will not greatly be diminished.

(*o*), the vehicle-mileage, for the 12 months, November 1876 to October 1877, was *not* given ;

(I). The vehicle-mileage was thus obtained :—

Gross goods vehicle-mileage, for the month = total goods train-mileage × number of goods vehicles in the train + mixed train-mileage due to goods × number of goods vehicles in the mixed train.

The train-mileage for—

Goods,	Maintenance,
Mixed (portion due to goods),	Miscellaneous,
Return empty,	

was taken from the audited weekly returns.

The composition of the train was taken from Table A-7 of the Review of the Revenue account for the half-years ending December 1876 and June 1877.

To the months—

July,	September,
August,	October,

of the year 1877, the figures (in respect to the composition of the train for the half-year ending December 1876) were applied.

(II). An attempt was made to obtain the goods ton-mileage from Table VI. by working through the invoices of the Eastern Bengal Railway for ten months, November 1876 to August 1877. The labour of going through this calculation was, however, saved by an artifice, explained in para. 10. The invoices consisted of twenty bundles of such a size that they filled a cab.

10. The method of application may be illustrated by an example, taken from the Eastern Bengal Railway.

From Table II. it may be seen that $\frac{v}{R}$ is a maximum in the half-year ending June 1877 ;* hence it is not necessary to consider any anterior period. To obtain with nicety the "*limit of work*" which can be got out of a vehicle, the *month* in which $\frac{v}{R}$ is a maximum should be known, and the figures for that month applied.

From Table VII., it will be seen that the Eastern Bengal Railway may practically be regarded as a line on which the traffic flows from one end

* The real maximum took place (*see* Table II.) in the half-year ending December 1873, and the figures for this half-year should properly be taken ; but as *no ton mileage* is given month by month for that half-year, it is better to take the half-year ending June 1877 (in which the traffic was certainly heavy), and the figures of the month of September 1877, which give a decided maximum. This is simply a matter of judgment and convenience.

only. This is the most adverse view of the traffic (*see* paragraph 6, clause *b*), and may therefore safely be adopted.

This view being accepted, that period in which the tons lifted is a maximum will also be that in which the ratio $\frac{v}{R}$ is a maximum. The labour of working out $\frac{v}{R}$ for ten months will (in this particular instance) be saved.*

A glance at Table VIII. shows that in the month of September 1877†, the maximum number of tons was lifted; hence, by what has been said, $\frac{v}{R}$ is a maximum in that month.

It is now established that—

(1). $\frac{v}{R}$ is a maximum for the half-year ending June 1877, (*see* Table II).

(2). „ „ month of September 1877† (*see* Tables VI. and VIII.)

11. In respect to the month of September 1877, we have—

$W = 9{\cdot}7$ tons (freight)‡
$w = 3{\cdot}5$ tons
$t = 7{\cdot}7$ days (Table VI.) = effective time
$s = 15$ miles per hour (Table V.)

Then, by paragraph 4, the work done by one wagon in one month is—

$$= W \times 24 \times t \times s = 9{\cdot}7 \times \overset{\text{hrs}}{24} \times 8 \times 15$$
$$= 27{,}936 \text{ gross-goods-ton-miles}:$$

* It must be understood that this artifice (for avoiding the labour of calculating $\frac{v}{R}$) is only allowable when the circumstances of traffic are as herein stated. If the traffic flows not only from end, but also from different points on the line, as in the case of the East Indian Railway, this artifice cannot be applied.

† Properly, a month of the half-year ending June 1877 should be taken; but it is manifestly best to work with the information that is most recent.

It is evident that the work done in September 1877, was *a* maximum; the monthly accounts (as stated in paragraph 9) are not at present rendered in such detail as to enable one to say whether it was *the* maximum work, or true limit of "work of a wagon". The method of procedure is however indicated in this Paper.

‡ According to the Review for the half-year ending December 1876—

The number of wagons *constructed* is	701
Add wagons borrowed in July 1877, from the Calcutta and South-Eastern State Railway, ...	40
Total goods rolling-stock in September 1877, ...	741

$$\text{Freight of a wagon} = \frac{\text{freight ton-miles}}{\text{vehicle-miles}} = \frac{6987442}{1987011} = 3{\cdot}51 \text{ tons, } \textit{see} \text{ Table VI.}$$

Weight of a wagon = 6·2 tons, *see* Table V.
∴ Weight of a wagon and its load = (6·2 + 3·5) = 9·7 tons.
Maximum freight ton miles of a wagon in one month.

$$\overset{\text{tons.}}{3{\cdot}5} \times \overset{\text{hrs}}{24} \times \overset{\text{days}}{8} \times \overset{\text{miles}}{15}$$
$$9880.$$

and the *additional* number of wagons required to do the *additional* work is—

$$= \frac{2638659 \text{ gross-goods-ton-miles}}{27{,}936 \text{ gross-goods-ton-miles}} = 94{\cdot}0 \text{ wagons, in addition to the 40 hired wagons.*}$$

12. In his letter No. 3759 of 5th October, 1877, the Agent, Eastern Bengal Railway, states that, to support a traffic 25 per cent. greater than that already on the line, he requires the goods-vehicles set forth in the following Table:—

	To Stations	Number of Trains			Number of Vehicles		
		To	From	Total	Per train	Total	Final total
Trains daily ...	Goalundo ..	5	5	10	40	400	480
reserve, ...	.....	..	..	..	..	80	
Trains daily ...	Kooshtea ..	1	1	2	40	80	96
reserve ..	.....	..	..	..	..	16	
Reserve for ...	Sealdah, Chitpore and Tramway,	..	..	..	..	120	120
Mixed train daily ...	Goalundo ..	1	1	2	30	60	72
						12	
Mail trains daily ...	Goalundo ..	1	1	2	30	60	72
reserve ...	.....	..	..	..	.	12	
Locomotive coal ...	.....	..	..	..	...	40	40
	Total number of goods-vehicles, ..						880
	For repairs, 5 per cent., ...						44
	Emergencies, ...						9
	Grand total number of vehicles, ..						933
	Deduct vehicles available on the line,†						658
Additional number of wagons required for the *additional* 25 per cent. of work,							275

13. Collecting the results in paragraphs 11, 12, and 13, it is seen that, to support an *additional* traffic equal to 25 per cent. of that of the half-year ending June 1877, the number of wagons required is—

* "In his letter No. 3759 of 5th October, 1877, the Agent, Eastern Bengal Railway, desired to have goods rolling-stock capable of carrying 25 per cent. more traffic than that already carried on the line."
Now, for the half-year ending June 1877—
The gross-goods-ton-mileage is, excluding engines and tenders, *see* Table M-1 of the Review of the Revenue Account, ... 63,327,814
and 25 per cent. which has to be carried in addition in 6 months is 15,831,953
" " " " in 1 month is 2,638,659

† This should be 701, *see* Table I.

94, by the formula, when the figures for the *month*, in which the strain on the rolling-stock (in a traffic sense) was greatest, is taken ; to this must be added 40 to replace the hired wagons.

282, when the Table of Trains given by the Agent is considered.

By paragraph (12), the *true* number of wagons required to do the *additional* work is (94 + 40) = 134, because that number is derived from figures showing the traffic of a period during which the strain on the rolling-stock (in a traffic sense) was greatest; or when the "*limit of work*" of a wagon was most nearly approached.*

The *work done* and the *intensity* with which the instrument (the rolling-stock) was used were (as seen from the Tables II. and VI). greater for the month of September, than for the half year ending June 1877.

If the intensity with which the instrument (the rolling-stock) was used in September 1877 could be sustained during the year, only 134 wagons would be needed *to do* 25 *per cent. additional work.*

The number 275 given by the Agent has been arrived at, as seen in paragraph 12 in manner more or less arbitrary; perhaps it includes 50 to replace the 50 ballast-wagons, which have been used for traffic.

14. The use of the formulæ set forth in paragraph 4, in *comparing* the work done on different railways, is strikingly shown in Table IV., where the work of the—

* This decides the number of *additional* wagons required to do 25 per cent *additional* work.
Inquiry may however be made as to the number of wagons required to do :—
(*a*), the *total* work that was done in the half-year ending June 1877 *plus* 25 per cent.
(*b*), the *total* work done in September 1877 *plus* 25 per cent.

Let N_1 = number of wagons required to perform the work, ...(*a*,
N_2 = ...(*b*),

Then $N_1 = \frac{5}{4} \times \frac{63327814 \text{ gross-goods-ton-miles. } \textit{See} \text{ page 8.}}{279{\cdot}36 \text{ gross-goods-ton-miles of one wagon per month} \times 6 \text{ months}}$
$= 472{\cdot}2.$

Hence in this case the Eastern Bengal Railway has—
$(701 - 472{\cdot}2) = 229$ wagons *too many*.

And $N_2 = \left(701 \text{ constructed} + 40 \text{ hired} + \frac{741}{4}\right)$ wagons = 926 wagons, is the real "*limit of work of the wagon*" has been reached.

Or, in this case, the Eastern Bengal Railway requires
(926 − 701) = 225 *additional* wagons, or 50 wagons less than the number *desired* by the Agent.

The request for more rolling stock, made by the Agent in his letter No. 3759 of the 5th October, 1877, may be interpreted in the sense of (*a*), or (*b*).

It may be surmised that it should be interpreted in the sense (*a*), as the Agent on the 5th October, 1877, could hardly have known the extent of the traffic in September 1877.

Whatever the interpretation, the *principle* of working is not affected.

East Indian* / Eastern Bengal } Railways is contrasted.

The economy which can be effected by the use of the three formulæ in paragraph 4 is evident; thus the Agent, Eastern Bengal Railway—

	£
(*a*), has obtained sanction for 200 iron rectangular wagons, none of which at present are erected, at a cost† of 200 wagons × 184·5	36,900
(*b*), has asked for sanction for 75 cylindrical wagons at a cost‡ of	13,410
Total expenditure sanctioned and that desired, ..	50,310
On the same basis, the cost of 134 iron cylindrical wagons shown by the formula to be sufficient (in place of 275 wagons) is wagons 134 × £180	£ 24,120

Hence in regard to the performance of *additional* work, equal to 25 per cent. of that done in the half-year ending June 1877§ by these formulæ, the saving—

	Saving in respect to wagons	
	Number	Cost
		£
(*c*), would have been, in respect to the 200 sanctioned wagons	46	8,280
(*d*), and will yet be, if the application for 75 more wagons be rejected, ...	75	13,410
Total saving (which could *have been*, and which *may yet be*, made) is, ...	121	21,690

Saving to such an extent as this is worthy of consideration.

15. In paragraph 1, it was stated that these formulæ were truly applicable when the line under consideration was, by reason of the traffic, *distressed for rolling-stock*.

It is manifest that the greater the amount of work done by one wagon, (*see* formula, paragraph 4,) the greater the need for rolling-stock. The formula, indicating the *work done by one wagon*, helps one to decide whether the application for more rolling-stock is justifiable, or not.

The circumstances of traffic being different, it will not be possible to

* The figures for the East Indian Railway are approximate only.

† By letter No. 3261 of 5th December, 1876, from the Government of India, the construction of 40 iron rectangular wagons at a cost of £7,381 was sanctioned. Hence the cost of one wagon is £184·5.

‡ *See* letter No. 3759 of 5th October, 1877, from the Agent, Eastern Bengal Railway.

§ It is not here considered whether the present stock is sufficient for the *total* work, namely, that done in the half-year ending June 1877 *plus* 25 per cent. *See* note to paragraph 13.

obtain equality of "*work done by one wagon*" among the different railways of India; nevertheless an approach to equality should be made; and unless the "work done by one wagon" (determined by the formula in paragraph 4) approaches to an equality with the maximum done on any railway, the application for more rolling-stock should be rejected, and the system on which the traffic is conducted be closely scrutinised.

Referring to Table IV., it will be seen that the mean measure of work done* by the—

East Indian Railway is $\frac{1}{15176} = \frac{1}{1}$ approximately,

Eastern Bengal „ „ $\frac{1}{7307} = \frac{1}{0{\cdot}41}$

or, the Eastern Bengal Railway, in half a year, does approximately one-half of the work effected by the East Indian Railway in the same period of time.

The reason is obvious for (*see* Table IV.) the detention in days per wagon is—

142·8 on the East Indian Railway, approximately,
157·5 „ Eastern Bengal Railway,

in the half-year ending June 1877.†

It is proper to mention that the Eastern Bengal Railway, has, but little traffic, save in the jute season—July, August, September and October.‡

* From the way in which this measure is obtained, it is to be remembered that the larger the denominator of the ratio, the greater is the work done.

† Or, it may be stated that, in the half-year ending June 1877, all wagons performed on the—

	hrs	miles per hr.	miles per day		days
East Indian Railway	24	× 17·6 =	422·4	for t =	38·2, approximately.
Eastern Bengal „	24	× 15·0 =	360·0	„ t =	23·4

From Table V., we know the gross load of a wagon.
Hence the gross ton miles, per wagon, per half-year June 1877, is—

	miles per day		days		gross load		gross ton miles
East Indian Railway =	422·4	×	38·2	×	10·5	=	169121·64
Eastern Bengal „ =	360·0	×	23·4	×	9·84	=	32892·16

‡ The maunds lifted (*see* Table VIII.) in—

	Maunds.
the 4 months, July, August, September, October 1877, ... =	5,614,320
the 8 months, November, December 1876, and January, February, March, April, May and June 1877, ... =	7,906,126
Total maunds lifted,... ... =	13,520,446

The proportion borne in—

the 4 months = $\frac{5,614,320}{13,520,446} = \frac{1}{2{\cdot}4}$ of the whole.

the 8 „ = $\frac{7,906,126}{13,520,446} = \frac{1}{1{\cdot}7}$ „ „

16. The formulæ may be used to determine the rate at which a home wagon shall be lent to a foreign line.

Let m, = time in months, c, = „ days } during which a home wagon is absent on a foreign line.

In T months, the detention in days when $\frac{v}{R}$ is a maximum, is D_d { the detention is not the same for every month.

which is known,

m, ——— $\frac{m}{T} \times D_d$,

Hence the actual *working* time in m, months, or c, days, is:—

$\left(c - \frac{m}{T} D_d\right)$ days.

And the *actual work*, which would be done by the home wagon in M, months, (at a time when $\frac{v}{R}$ was a maximum,) if it remained on the home line is:—

Hrs. Miles per hour. Days.

$= 24 \times s + \left(c - \frac{m}{T} D\right) \times w = P$ freight ton miles.

Let (a) = proper rate in pies per ton-mile for home goods wagon lent to the foreign line. Then for the time m, months (*whether the ton-miles* P *be performed or not*) the charge per wagon, lent to the foreign railway, should be—

Ton miles. Pies.

$= P \times a = a P$ pies.

The proper value of (a) is set forth below:—

The value of (a) per ton-mile *	Railways		Per ton-mile.
	Eastern Bengal	East Indian	
Must be greater than, ..	0·051	0·08	Cost of repairs.
Ditto do., ..	9·06	9·2	Lowest rate of carriage.
Ditto less than, ..	54·4	27·36	Highest rate of carriage.
Deduction from (a) for locomotive expenses for haulage, ..	0·45	0 24	

* By page 8 of the Goods Tariff of the Eastern Bengal Railway, the heaviest rate is the fifth class, which is 2 pies per maund per mile.

Remembering that 1 maund = 0·03673 tons,

the rate per ton-mile = $2 \times \frac{1}{0{\cdot}03673 \text{ tons}}$ pies = 54·4 pies.

The *actual* hire which should be charged by the Eastern Bengal Railway for wagons borrowed by a foreign Railway may be found as follows:—

Let P = 9,880 freight ton-miles, *see* note to paragraph 11, page 7.
Then the charge per wagon to a foreign line must lie between—

Pies		freight Ton-miles,		Rs.		Rs.
(9·06	− 0·45) ×	9,880	=	443	per month, or	14·8 per day,
and (54·4	− 0·45) ×	9,880	=	2,776	„ or	92·5 „

It may be thought that these charges are *imaginary*—but they are not really so.

On the Eastern Bengal Railway, an iron cylindrical wagon earns, in the brisk season, Rs. 50 a day*; and it is certain, that, if the character of the

The lowest ordinary rate is ½ pie per maund per mile.

Hence the rate per ton-mile = ½ pie × $\frac{1}{0{\cdot}05673 \text{ tons}}$ =

From abstract C of the Revenue Account for the half-year ending June 1877.

The cost of wagon-repairs per ton-mile = $\frac{22{,}076 \text{ Rs.}}{70{,}811{,}423 \text{ ton-miles (approximate)}}$ = 0·051 pies.

By page 17 of the Goods Tariff of the East Indian Railway, the fifth class or highest rate, is Rs. 500 for 100 maunds carried 954 miles.

Hence the rate per ton-mile = $\frac{500 \text{ Rs.}}{3{\cdot}673 \text{ tons} \times 954 \text{ miles}}$ = 27·36 pies.

The lowest ordinary rate is Rs. 168 for 100 maunds carried 954 miles.

Hence the rate per ton-mile = $\frac{168 \text{ Rs.}}{3{\cdot}673 \text{ tons} \times 954 \text{ miles}}$ = 9·2 pies.

From Abstract C of the Revenue Account for the half-year ending June 1876 for the Main Line.

The cost of wagon repairs per ton-mile = $\frac{3{,}57{,}478 \text{ Rs.}}{85585129 \text{ ton-miles}}$ = 0·08 pies.

From Abstract B of the Revenue Account and Table M-1 of the Review for the half-year ending June 1877, the Locomotive expenses for haulage per gross ton mile are—

1). From the Eastern Bengal Railway = $\frac{1{,}64{,}850 \text{ Rs.}}{69501069 \text{ gross ton-miles}}$ = 0·45 pies.

* Minute of a conversation with the Assistant Locomotive Superintendent, Eastern Bengal Railway, at the Workshops, Kanchrapara, in November 1877

The rate per wagon, per month, *may* be found from the ton-mileage of the half-year instead of from a *particular* month, during which the traffic was very brisk. Thus the charge per wagon would be:—

$\frac{70{,}811{,}423 \text{ ton miles (Table II.)}}{6 \text{ months} \times 791 \text{ wagons}}$ × 9·06 pies, = Rs. 87·06 per month, or Rs. 2-9 per

should be deducted haulage, or Locomotive expenses, per ton mile), which is certainly an o

The truth is, the rate of hire should properly be worked out for every month of the year. If the Guaranteed Railways have not suffered loss from lending their wagons to foreign lines at Rs. 1½ Rs. 2, or Rs. 3, per wagon, per diem, it is because they have *borrowed* as many as they have lent.

bulk of their merchandise were such as to be charged 54·4 pies per ton-mile it would not be proper to let a wagon to a foreign line at less than Rs. 92·5 per day.

It is rarely, however, that the bulk of the traffic is of such a kind as be so chargeable.

It may be said that each class of goods Rolling Stock should separately be considered. Strictly this is true and it might be done; but it would add greatly to the labour of finding the time when $\frac{r}{R}$ is a maximum, and the advantage of this refinement of calculation would not be great.

Each particular class of vehicle is designed to perform maximum work in its own line; it is by each class doing its maximum, that a total real maximum is reached. Consider the ballast-wagons,—these were largely employed in the transport of Railway Stores; and it is probable that, used in this way, they performed their true share of work.

Cattle wagons might fairly have been excluded; but their number is so small as not materially to affect the question. Brake-Vans should perhaps have been excluded, yet each carries 5 tons freight.

The example in this paper is given simply by way of illustration.

17. In drawing up this Paper, and in framing the Tables, care has been taken to give all references, so as to render the process of calculation as easy as possible; and to secure accuracy in the tabulation of the figures.

The Reader is invited rather to consider the principle [*i. e.*, the use of $\frac{r}{R}$] set forth in this Paper, than to scrutinize the figures.

H. W. C.

CALCUTTA,
27th November, 1877.

TABLE I.

EASTERN BENGAL RAILWAY.

Showing the capacity of the goods rolling stock for 15-half years.

See column 2 of Table 12 of the Revenue Account or Table G-1 of the Review of the Revenue Account.

	HALF YEAR ENDING																							
	1870						1871						1872						1873					
	June			December			June			December			June			December			June			December		
	No. constructed	Capacity	Total tons	No. constructed	Capacity	Total tons	No. constructed	Capacity	Total tons	No. constructed	Capacity	Total tons	No. constructed	Capacity	Total tons	No. constructed	Capacity	Total tons	No. constructed	Capacity	Total tons	No. constructed	Capacity	Total tons
ared goods wagons,	461	9·1	4195·1	461	9·1	4195·1	461	9·1	4195·1	461	9·1	4195·1	460	9·1	4186·0	460	9·1	4186·0	460	9·1	4186·0	398	9·1	3621·8
ds break-van, ..	10	9·5	95·0	10	9·5	95·0	10	9·5	95·0	14	9·5	133·0	16	9·5	152·0	16	9·5	152·0	16	9·5	152·0	16	9·5	152·0
le wagons, ..	19	3·5	66·5	19	3·5	66·5	19	3·5	66·5	19	3·5	66·5	19	3·5	66·5	19	3·5	66·5	19	3·5	66·5	19	3·5	66·5
h-sided wagons, ..	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2
e wagons,.. ..	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4
l „	7	11·1	77·7	7	11·1	77·7	7	11·1	77·7	7	11·1	77·7	7	11·1	77·7	7	11·1	77·7	7	11·1	77·7	7	11·1	77·7
last „	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0
aber trucks, ..	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5
a cylindrical wagons	..	9·5	..	..	..	..	10	9·5	95·0	60	9·5	570·0	80	9·5	760·0	80	9·5	760·0	142	9·5	1349·0	142	9·5	1349·0
indrical simple „	..	10·0	..	..	..	..	..	..	..	1	10·0	10·0	2	10·0	20·0	2	10·0	20·0	2	10·0	20·0	2	10·0	20·0
TOTAL, ..	640	..	5975·4	640	..	5975·4	650	..	6070·4	705	..	6593·4	727	..	6803·3	727	..	6803·3	789	..	7392·3	727	..	6828·1

	1874						1875						1876						1877					
vered goods wagons,	358	9·1	3257·8	355	9·1	3257·8	346	9·1	3148·6	346	9·5	3287·0	346	9·5	3287·0	346	9·5	3287·0	346	9·5	3287·0	..	..	..
ods break-van, ..	16	9·5	152·0	13	9·5	123·5	13	9·5	123·5	13	9·5	123·5	13	9·5	123·5	13	9·5	123·5	13	9·5	123·5	..	..	..
ttle wagons, ..	19	3·6	66·5	4	3·5	14·0	4	3·5	14·0	4	26·3	10·5	10	26·3	26·3	10	26·3	26·3	4	26·3	10·5	..	..	..
igh-sided wagons, ..	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	76	10·7	813·2	..	..	..
ke wagons,.. ..	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	2	10·2	20·4	..	..	..	..	..	..
al „	7	11·1	77·7	7	11·1	77·7	4	11·1	44·4	4	11·1	44·4	7	11·1	77·7	7	11·1	77·7	..	..	..	..	..	..
allast „	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	50	11·3	565·0	..	..	..
imber trucks, ..	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	15	9·5	142·5	..	..	..
on cylindrical wagons	157	9·5	1491·5	182	9·5	1729·0	194	9·5	1843·0	194	9·5	1843·0	194	9·5	1843·0	194	9·5	1843·0	194	9·5	1843·0	..	..	..
mple „ ..	2	10·0	20·0	2	10·0	20·0	2	10·0	20·0	2	10·0	20·0	2	10·0	20·0	2	10·0	20·0	2	10·0	20·0	..	..	..
ostal vans, ...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
owder van, ...	..	..	..	1	9·5	9·5	1	9·5	9·5	1	9·5	9·5	1	9·5	9·5	1	9·5	9·5	1	..	9·0	..	..	..
TOTAL, ..	702	..	6606·6	710	..	6772·6	707	..	6744·1	707	..	6879·0	716	..	6928·1	716	..	6928·1	701	..	6813·7	..	..	..

TAI

EASTERN BEN

Showing the work done in the 14 *half-y*

	Symbol		HALF-YE					
		1870		1871		1872	
		June	December	June	December	June	Dece
o. of goods vehicles, ...		640	640	650	705	727	
Table 12 *of Revenue Account.*							
o. of covered goods wagons, ...		461	461	461	461	460	
). of iron cylindrical wagons, ...		*Nil*	*Nil*	10	60	80	
ıpacity in tons, ...		5,975	5,975*	6,070	6,593	6,803	(
Table 12 *of Revenue Account, Table G-1 of the Review, and Table I of this Note.*							
ain-mileage, Goods, ...		..	..	..	..	..	..
Table D-1 Footnote of the Review.							
in-mileage, ...		..	53,443,195	54,838,700	45,048,548	62,285,626	70,72
). Coaching and goods.							
Item 27 *of Table M-1 of the Review.*							
). Gross goods only, ...		..	39,368,815	37,790,092	28,908,665	41,869,142	50,73
Items 19 *and* 26 *of Table M-1 of Review.*							
). Goods, Up, ...		..	..	..	..	..	..
Table C of Review.							
. Goods, Down, ...		..	..	..	..	..	..
hicle-mileage, goods (including brakes),	v	..	3,760,802	3,723,979	2,808,975	3,853,683	4,632
Table G-11, or items 14 *and* 16 *of Table M-1 (previously to December* 1874) *of the Review.*							
io of $\frac{\text{freight ton capacity of goods vehicles}}{\text{gross goods ton-mileage}}$	$\frac{1}{R}$	..	1 6588·1	1 6227·2	1 4384·7	1 6154·5	1 7457
io of $\frac{\text{energy with which the stock was worked}}{\text{measure of work done}}$	$\frac{v}{R}$	..	570·8	598·0	640·6	626·2	621

* This should be

II.

RAILWAY.

December 1870 *to June* 1877.

ENDING									
1873		1874		1875		1876		1877	
June	December	June	December	June	December	June	December	June	December
789	727	702	710	707	707	716	716	701	..
460	398	358	358	346	346	346	346	346	..
142	142	157	182	194	194	194	194	194	..
7,392	6,828	6,606	6,773	6,744	6,879	6,928	6,928	6,805*	..
149,444	167,879	134,346	128,748	98,814	122,362	116,523	144,867	148,865	..
68,425,121	71,635,296	81,151,421	78,377,034	68,618,852	72,654,636	69,501,069	90,861,504	..	..
43,826,467	39,400,495	58,953,696	55,298,169	43,954,132	49,358,048	44,781,182	68,092,350	63,327,814†	..
..	3,462,604	9,660,530	3,078,117	2,901,498	2,135,424	2,350,830	3,786,006	4,183,510	..
..	13,075,096	14,762,881	14,901,521	10,148,534	13,140,151	11,297,008	18,937,444	18,941,083	..
4,138,616	4,250,937	4,592,210	4,622,932	3,364,367	3,928,278	3,690,803	5,491,647	5,916,694	..
1	1	1	1	1	1	1	1	1	..
5928·9	5770·4	8924·3	8164·5	6517·5	7175·2	6463·8	9828·5	92944·1	..
698·0	786·7	514·6	566·2	516·2	547·5	571·0	558·8	636·6	..

for this half-year had not been prepared when this paper was written.

TABLE III.

Eastern Bengal Railway.

Statement showing the mean-work of several half-years.

(Taken from Table II. of this paper).

	What half-years	Number of half-years	Total	Mean
Number of goods vehicles, ...	June 1870 to June 1877, ...	15	10,564	704
Capacity of goods vehicles in tons, ...	June 1870 to June 1877, ...	15	100,103	6,673
Train-mileage—				
Goods, ...	June 1873 to June 1877, ...	9	1,211,850	134,650
Ton-mileage—				
(*a*)—Coaching and goods, ...	December 1870 to December 1876 ...	13	887,563,082	68,274,083
(*b*)—Goods only, ...	December 1870 to June 1877, ...	14	682,655,261	48,761,090
(*c*)—Up, ...	December 1873 to June 1877, ...	8	31,558,519	3,944,815
(*d*)—Down, ...	Ditto ditto, ...	8	115,203,718	
Vehicle-mileage—				
Goods, ...	December 1870 to June 1877, ...	14	58,776,183	4,198,299
Ratio of $\frac{\text{mean freight ton-capacity of goods vehicles}}{\text{mean gross goods ton-mileage}}$	$= \frac{6,673}{48,761,090}$		$= \frac{1}{7,307\cdot2}$	

TABLE IV.

Giving a comparison between the Work done by the East Indian Railway and that by the Eastern Bengal Railway, by means of the ratio of $\frac{\text{capacity of goods stock}}{\text{goods ton-mileage}} = \frac{1}{R}$

(Taken from Table II. of this Note, and Table XI. of a Note, dated 21st July 1877, by Captain Clarke, R.E., on the "work done by" the East Indian Railway.)

RAILWAY	HALF-YEAR ENDING															
	1870		1871		1872		1873		1874		1875		1876		1877	
	June	December	June	December	June	December	June	December	June	December	June	December	June	December	June	December
East Indian capacity of goods stock / gross goods ton-mileage = 1/R	...	...	...	1 / 16,063·0	1 / 14,342·1	1 / 11,016·1	1 / 16,078·4	1 / 15,756·4	1 / 24,957·2	1 / 14,441·0	1 / 13,287·0	1 / 10,895·7	1 / 15,877·5	1 / 15,143·8		
Detention in days per wagon, ...	...	...	...	...	...	...	158·6	162·4	145·6	161·2	156·2	163·9	152·4	155·7	142·8	
Eastern Bengal capacity of goods stock / gross goods ton-mileage	...	1 / 6588	1 / 6227	1 / 4885	1 / 6154	1 / 7457	1 / 5929	1 / 6770	1 / 8924	1 / 8164	1 / 6517	1 / 7175	1 / 6464	1 / 9828	1 / 10320	
Detention in days per wagon. Table V., ...	...	...	...	...	...	...	166·4	167·8	162·8	165·9	167·9	168·6	166·7	162·2	157·5	

Mean ratio of $\frac{\text{freight ton-capacity of goods stock}}{\text{gross goods ton-mileage}}$ $\frac{1}{15,176·6}$ for the East Indian Railway.

" " " " " $\frac{1}{7,136}$ " Eastern Bengal "

Note.—The *difference* of time in days that each wagon was detained accounts in a great measure for the difference in *work done*.

The value of $\frac{1}{R}$ for the East Indian Railway is taken from Table XI. of a "Note" on the work done by the East Indian Railway, and may be considered approximately correct

The detention in days is for the East Indian Railway only approximate.

TABLE

EASTERN BENGAL

Showing the detention

	Symbol	Half year 1873 June	1873 December	1874 June	1874 December
No of vehicles constructed, ...	S	789	727	702	710
Table G–I of the Review, or Table XII. of Revenue Account, ...					
Vehicle-mileage—					
(*a.*) *Total* which could possibly be run, if the vehicle ran all day and every day, at "between station" mile per hour, ...	V	51,411,240	48,156,480	45,742,320	47,030,400
(*b.*) *Actual* Table G-11 of the Review or Table II. of this Note, ...	v	4,138,616	4,250,937	4,592,210	4,622,932
Difference or *detention* in the half-year reckoned in—					
(*c.*) Vehicle-mileage, ...	D_v	47,272,624	43,905,543	41,150,110	42,407,468
(*d.*) Days per wagon, ...	D_d	166·4	167·8	162·8	165·9
Average speed in miles of goods train. *Table F. of the Review.*					
(*f.*) Between stations, ...	*s*	15½ *to* 21½	15·0	15·0	15·0
(*g.*) Through, ...	..	13½ *to* 17½	15·0	15·0	15·0
No. of *working days*, or days during which the vehicles ran continually through the 24 hours of a day at a speed *s*, ...	*t*	14·6	16·2	18·2	18·1
Weight in tons of a wagon, ...	*w*	6·2	6·2	6·2	6·2
Table A–8 of the Review of the Revenue Account.					
Weight in tons of a wagon and its load, ...	W	10	10	10	10·3

The Goods vehicle mileage is that shown in Table G-11 as *paying*, only; it should have been that *paying* Account.

For the half-year ending { June 1873 / December 1873 / June 1874 } the Goods vehicle mileage shown in items 14 and 16 of the heading "total mileage of each description of stock" has not been framed.

It will be seen by referring to latter Reviews of the Revenue Account that these or corresponding items G-11 of the Review of the Revenue Account.

For the half-year ending June 1877 from Tables G–1 and M–1 of the Review of the Revenue Account, the

		Freight tons
(324·21 + 47·63 + 1 + 13·26 + 184·62)	goods vehicles	× 4·01
67·76	mineral	× 3·867
4	cattle	× 1·177

Total load of vehicles in working order,

Hence the average freight—

Per vehicle in working order $= \frac{2555·323}{658·485}$

„ constructed $= \frac{2555·323}{701}$

Similarly for the half-year ending June 1877,

The freight—

Per vehicle in working order is

„ constructed „

V.

of goods vehicles.

ENDING						OF 9 HALF-YEARS	
1875		1876		1877			
	December	June	December	June	December	Total	Mean
707	707	716	701	701	..	6,460	717·8
46,068,120	46,831,680	46,654,560	46,434,240	45,677,160	..	424,006,200	47,111,800
3,364,267	3,928,278	3,690,803	5,491,647	5,916,694	..	39,996,484	4,444,054
42,703,753	42,903,402	42,963,757	40,942,593	39,760,466	..	384,009,716	42,667,746
167·8	168·6	166·7	162·2	157·5	..	1485·8	165·1
15·0	15·0	15·0	15	15			
15·0	15·0	15·0	15	15			
13·2	15·4	14·3	21·8	23·4	..	155·2	17·2
6·2	6·2	6·2	6·2	6·2	..	55·8	6·2
10·3	10·2	10·1	10·6	10·0	..	91·2	10·2

and *free*, in Table G-11. of the Review of the Revenue

Table M-1 of the Review of the Revenue Account under
been used, because, in those half-years, Table G-11 had

agree with the Goods *vehicle* mileage given in Table

$D_t = (V - v)$

$$D_d = \frac{D_t}{S \times s \times 24 \text{ hours}}$$

t = number of days in a half-year $(T - D_d)$.

verage freight of a wagon is thus found :—

Freight tons
= 2288·577
= 262·028
= 4·708

= 2555·323

= 3·9 tons.

= 3·645 „

for the East Indian Railway.

·22 tons.
·84 „

TABLE

EASTERN BENGAL

Showing per month, for a period of 12 *months, the vehicle-mileage*

(Taken from the audited

	Symbol	1876 November	December	January	February
Goods train mileage, ...	..	23,734	26,408	26,598	23,095
Mixed train mileage, ...	..	16,143	16,536	16,704	15,022
Goods train mileage due to goods portion of mixed train, ...	..	6,649	6,811	..	..
Freight ton-mileage, ...	..	..	..	..	..
Goods vehicle mileage—					
(1). Total which could possibly be run if the vehicle ran all day at "between station speed" (*s* miles) per hour, ...	V	7,732,800	7,990,560	..	..
(2). Actual vehicle mileage, { Goods, ...	..	908,062	1,018,370	..	..
{ Mixed (due to goods),	..	104,788	107,341	..	..
Total goods vehicle mileage, ..	*v*	1,012,850	1,125,711	..	..
Detention reckoned in—					
(1). Vehicle mileage, ...	D_v	6,719,950	..	..	..
(2). Days per wagon, ...	D_d	26·07	26·63	..	..
Number of working days in the month, or days during which the vehicles ran continually at "between station speed (*s* miles) per hour, ...	*t*	3·9	4·4	..	..
Tons lifted, ...	..	32393	34853	..	..
Ratio of—					
(1). $\frac{\text{Freight ton capacity of goods stock,}}{\text{Freight goods ton-mileage,}}$ ..	$\frac{1}{R}$	..	..	..	..
(2). $\frac{\text{Energy with which rolling stock was worked,}}{\text{Measure of work done,}}$ ..	$\frac{v}{R}$	..	..	..	..

From Table A7 of the Review of the Revenue Account for the half-year ending—

December 1876, the number of vehicles, including brakes in a train was, ...

June 1877, ...

The goods train-mileage due to mixed trains for the half-year ending—

December 1876 = mixed train mileage $\times \frac{15{\cdot}76}{38{\cdot}26}$

June 1877 = „ $\times$ } In default of better data, the figures (as

half-year ending December 1877.

Goods vehicle mileage = (goods train mileage × number of goods vehicle in a goods train + mixed

$D_d = (V - v)$

$D_d = \frac{D_v}{S \times s \times 24 \text{ hours.}}$

The value of $s = 15$ miles per hour.

„ „ $S = 716$ for each of the months November, December 1876

See Table No. 12 of the Revenue Account for

VI.

RAILWAY.

ton-mileage, and ratio of $\frac{\text{energy with which the goods Rolling Stock was used.}}{\text{measure of work done.}}$
weekly returns).

1877							
March	April	May	June	July	August	September	October
28,367	30,779	34,377	30,764	42,415	48,376	49,224	48,718
16,704	15,975	16,704	16,143	16,536	16,582	15,975	16,703
..	..	..	..	6,811	6,830	6,580	6,883
..	..	..	..	..	..	6,987,442	6,521,794
..	..	..	..	7,990,560	7,990,560	7,732,300	..
..	..	..	..	1,622,798	1,850,866	1,888,410	..
..	..	..	..	107,341	107,641	103,701	..
..	..	..	..	1,730,139	1,958,507	1,987,011	..
..	..	..	..	6,260,421	6,032,053	5,745,789	..
..	..	..	..	21·29	23·4	22·29	..
..	..	..	..	6·7	7·6	7·7	..
..	..	..	..	..	..	..	..
						6,814 1	6,814 1
..	..	..	..	..	..	6,987·442 = 1025·4	6,521,794 = 957
..	..	..	..	..	..	1933·8	..

	Passenger.	Mixed.	Goods.
.. ..	15·61	{ 15·76G / 6·38P }	38·26
.. ..	?	?	?

regards the number of vehicles in a train) for the half-year ending December 1876, are to be applied to the

train mileage due to goods × number of goods vehicles in a mixed train).

July, August and September 1877.
the half-year ending December 1876.

Table VI., *see* paragraph 10.

TABLE VII.

Eastern Bengal Railway.

Showing the ratio of $\frac{\text{up ton-mileage}}{\text{down ton-mileage}}$

Taken from Table C of the Review of the Revenue Account.

Half-year ending	Ton-miles.		Ratio of up ton-miles / down ton miles.
	Up.	Down.	
December 1873, ...	1,654,962	13,060,306	$\frac{1}{7\cdot8}$
June 1874, ...	8,344,731	14,752,851	$\frac{1}{1\cdot9}$
December 1874, ...	2,624,409	14,884,478	$\frac{1}{5\cdot6}$
June 1875, ...	2,750,069	10,077,785	$\frac{1}{3\cdot6}$
December 1875, ...	1,968,147	13,098,857	$\frac{1}{6\cdot6}$
June 1876, ...	2,167,248	11,156,529	$\frac{1}{5\cdot1}$
December 1876, ...	3,545,739	18,859,527	$\frac{1}{5\cdot3}$

TABLE VIII.

Eastern Bengal Railway.

Showing the weights carried in the weekly periods of 12 *months, November* 1876 *to October* 1877.

(Taken from the audited Weekly Returns)

Month	No. of days	Maunds	No. of days	Maunds	No. of days	Maunds	No. of days	Maunds	No. of days	Maunds	No. of days	Maunds	No. of days	Total maunds for the month
1876.														
November, ...	4	127,589	7	218,180	7	220,417	7	192,946	5	115,615	..	..	30	881,747
December, ...	2	54,064	7	200,066	7	206,581	7	200,066	7	234,122	1	53,794	31	948,693
1877.														
January, ...	6	163,669	7	200,701	7	142,369	7	176,463	4	62,433	..	..	31	753,635
February, ...	3	99,879	7	175,481	7	197,391	7	255,631	4	119,220	..	..	28	847,605
March, ...	3	107,908	7	179,778	7	203,267	7	211,429	7	233,092	..	..	31	935,474
April, ...	7	188,498	7	292,643	7	257,655	7	303,881	2	75,738	..	..	30	1,118,415
May, ...	5	228,636	7	290,346	7	275,962	7	256,492	5	203,323	..	..	31	1,254,759
June, ...	2	83,631	7	276,423	7	265,049	7	246,679	7	294,018	..	..	30	1,165,798
July, ...	7	212,449	7	319,082	7	304,310	7	353,929	3	145,089	..	..	31	1,334,859
August, ...	4	182,788	7	323,047	7	358,969†	7	286,117	6	283,016	..	..	31	1,433,939
September, ...	1	60,706*	7	315,717	7	329,730	7	345,037	7	351,186	1	57,342	30	1,459,718‡
October, ...	6	311,901	7	358,014	7	301,760	7	241,458	4	172,671	..	..	31	1,385,809

	Maunds.		
Total maunds ..			13,520,446
Mean maunds per month ..			1,126,703

* The day in which the greatest quantity (60,706) was carried is 1st September, 1877.
† „ week „ „ (358,969) „ „ 11th to 18th August, 1877.
‡ „ month „ „ (1,459,713) „ „ September 1877.

No. CCLXX.

JEYPORE CHURCH—RAJPOOTANA.

[*Vide* Frontispiece and Plates I.—IV.]

By Capt. S. S. Jacob, R.E., *Exec. Engineer.*

In any design for a Church in India several points have to be considered which are not necessary in a colder climate, and the difficulty is to combine these peculiarities in such a way as not to impair efficiency and at the same time to be in keeping with a style, with which all our feelings of devotion are associated.

There must be the means of adjusting the entrance of light so that while there shall always be sufficient, yet the sun's rays and heat and the glare shall be excluded.

There must be means of ventilation, sometimes to admit the air, so as to create a thorough draught and sometimes to exclude it altogether. If Tatties are used, they must be where they can be easily watered without disturbing the congregation, must not exclude the light, and must be so distributed as to be effective.

The Punkahs should have a good swing, and should admit of being all pulled in unison without any sound whatever, and should be of a neat design suitable to a sacred building, and not like the articles so often seen and so distracting. The acoustic properties should be considered, where often all doors and windows are open. The doors or windows should, if possible, be so designed as to secure privacy and prevent interruption from persons outside, so as to assist concentration of thought in the worshippers. The seats should not be too close in a hot climate, and should admit of a person listening to or offering prayer without discomfort.

All woodwork in the doors or windows should, as much as is possible, be protected from the weather and the sun. Everything about the build-

ing should be thoroughly good of its kind, and as unperishable as possible—in order that the ravages of white ants or insects may be guarded against and repairs be seldom or never necessary.

This Church has been built in the early English style—and it is believed that all these points have been attended to—while at the same time there is nothing about it, nor in any of its details, inconsonant with this style and feeling.

It is intended to provide for 100 sittings. The design comprises a nave (55′ × 16′) and two side or verandah aisles 8 feet wide. In the second bay from the west end in each of these aisles is an entrance doorway 5 feet wide, protected from the sun and weather by a porch (7′ × 6′) in which are side seats for the use of any one obliged to wait at any time. Over the entrance porches are marble panels bearing this inscription, "Enter into his courts with Praise". The quatre foil openings over the side seats are filled in with red sandstone tracery, showing the sacred monogram. Over the doors inside are the words, "Draw nigh to God and He will draw nigh to you". "Him that cometh to me I will in no wise cast out".

The Font is placed near the west end where a line from the middle of the first bays intersects the centre line of the building. It is entirely of polished marble, and was made in Jeypore. It is the gift of a friend. Round the plinth is the inscription, "And Jesus took them up in His arms and blessed them".

The two last or east bays are separated from the nave by the chancel arch and side walls. This forms the Chancel, which is raised by a step of 6 inches above the nave. The chancel space is about 14′ × 12′ with a raised apse beyond. The portions of the aisles, which are enclosed, form the Vestry on one side, and space for the harmonium on the other, each 12′ × 8′. They are fitted with window-seats, shelves and hooks, and the arched opening which connects each with the nave is provided with a brass rod and curtain, which can be drawn when necessary. Over the chancel arch is the text, "O send out Thy Light and Thy Truth—let them lead me".

The Apse is rather more than half an octagon and provides a space of 19½′ × 8′, which gives room for the Communion Table, and allows space for officiating Clergymen to pass each other without inconvenience.

Altar Rails are ornamental polished brass standards fitted into a

continuous marble base—and mounted by a shīsham wood handrail—the centre portion of which is fitted with a brass hinge to fold back horizontally.

The Altar chairs are of the Glastonbury pattern, of dark shīsham wood, fitted with plain red cushions for the back panel and seat.

The apse is lighted by three windows, one in each face of the apse, placed at a height of 10 feet above the floor. This prevents any inconvenience from the sun at the Morning Services, which, in some Churches in India, owing to a large low east window, is unbearable.

The windows in the aisles are somewhat similar to the windows in the Bishop's Palace, Wells. They are provided with comfortable seats. The lights are closed with wooden venetians which can be adjusted as required, or opened altogether if desired. The quatre foil head opening is closed with plain glass at present. It is hoped that these quatre foils and the windows in the apse may be filled in eventually with stained glass. The openings below the seats are at present closed with slate slabs and inside with iron bars. If it is desired to have a current of air, these slabs can be removed, or tatties can be placed in these openings if necessary; being near the ground they could be easily kept wet.

The windows outside are protected from the sun and weather by projecting slabs supported on stone brackets, which throw a deep shade over the windows. From the outer edge of the sunshade wire netting is attached to the ground to enable evergreen creepers to climb and by hanging over, in festoons, add to the general appearance and afford a grateful shade.

In the west end wall above the font is a handsome stained glass rose window 6 feet in diameter, somewhat after a circular window in Peterborough Cathedral. The mullions are of white marble. The window was prepared by Ballantine and Son of Edinburgh from designs furnished here.

The Reading Desk is from a design of Dr. DeFabeck, and was made in the Jeypore School of Industrial Art.

The shafts of the pillars supporting the nave arches are circular of polished red marble and contrast well with the caps and bases, which are of dressed stone of a light gray colour unpolished.

All the interior archwork in the Church (from want of Funds) is of slabstone with plaster mouldings.

The chancel arches spring from handsome marble corbels.

The roof is a peculiar feature. Good wood is not to be had here except

at a great cost, while good slabs are to be had in abundance and up to lengths of 20 feet or so. The slabs are a mica schist and vary from 12 to 15 inches in width and from 9 to 12 inches in depth. When plastered they form an imperishable roof, and underneath look clean and neat.

This Church has been roofed with these slabs. The height of the aisles is 17 feet, and of the nave 29 feet.

The nave roof is supported by drop arches which spring from cut stone corbels in the spandrels above the nave pillars, and the slabs rest longitudinally with the building, from arch to arch. The roof has a rise of one foot in the centre to throw off the rain. There are hooks in the roof, from which ornamental pankahs are hung by fine wire: the pankahs are all attached to a light frame, and one man from the west end wall can pull them all together in unison. This obviates what is so often seen in Indian Churches—pankahs moving to and fro at irregular intervals.

The height of the nave admits of a row of clerestory windows on each side in the main wall above the verandah roof—outside, these are protected by projecting sunshades of red sandstone, and the quatre foil openings are closed by perforated zinc wire, to allow of ventilation but keep out the birds.

There has been no attempt at interior decoration from want of Funds.

The general appearance outside can be seen from the drawings—want of money has prevented expenditure on carving or ornament.

At the east corner of the south aisle is the Tower or Belfry. The lower portion at the level of the parapet of the aisle, is ornamental with lozenge work in white and black marble, with a triangular pattern in red sandstone. In the belfry there are louvred trefoiled openings to allow of the free circulation of sound—above the belfry is an open lantern and small spire of cut stone surmounted by an iron finial.

The canopy of the windows in the apse has below it a dog-tooth ornament in pure white marble in a hollow moulding—the supporting shafts are also in white marble.

To finish off the copings of the walls instead of a corbel table and parapet, a light projecting *chhajjā* or sunshade in red sandstone has been adopted, supported by red stone brackets, as being more in keeping with this climate where deep shadows are required, and to throw the rain off the walls, which it does most effectually.

The Maharajah of Jeypore gave the ground and Rs. 3,000 towards the erection of this Church.

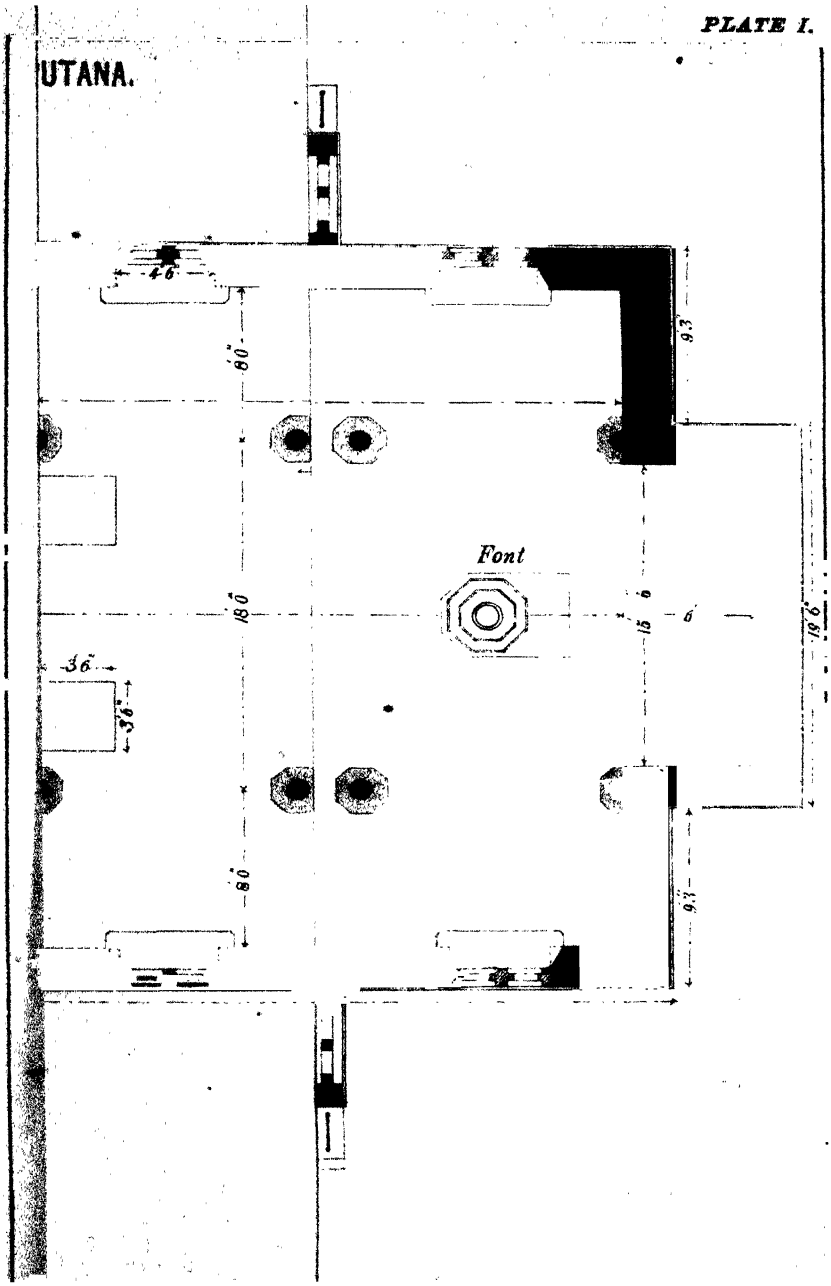
The specification is omitted to save space. The Abstract of the actual cost is attached:—

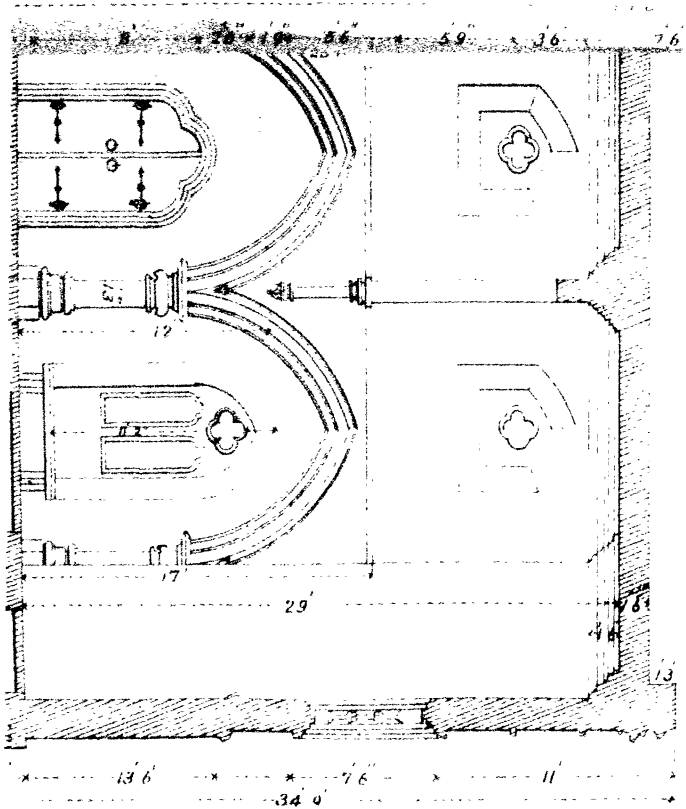
ABSTRACT.

c. ft.		Rs.
2,532	Concrete foundation, at Rs. 9-6-5 per 100, ...	238
15,367	Rubble masonry, at Rs. 16-8-9 per 100, ...	2,543
2,490	Cut stone Annagarh gray stone, at Rs. 1-12-5 per foot, ...	4,428
s. ft.		
199	Doors and windows of shisham, at Rs. 3-8 per foot, ...	697
c. ft.		
460	Cut stone work, red sandstone, at Rs. 3-4-1 per foot,... ...	1,499
190	Coloured marble work, at Rs. 5-4-8 per foot, ...	1,005
1,075	Slabstone archwork with centrings, at Rs. 54-8 per 100, ...	586
r. ft.		
915	Slab cornice and moulding in plaster, at Rs. 0-8-6 per foot, ...	488
No.		
4	Red sandstone quatre foil tracery, at Rs. 12-6-5 each, ...	50
r. ft.		
15	Tooth ornament over apse windows in white marble, at Rs. 11-6-6 per foot, ...	171
s. ft.		
2,671	Terraced roofing, at Rs. 48-7-6 per 100, ...	1,295
2,230	Terraced floor, at Rs. 9 per 100, ...	201
13,273	Plaster, including lettering, &c., at Rs. 2-13-9 per 100, ...	380
11,075	White and colour washing inside, at As. 0-7-10 per 100, ...	54
No.		
1	Rose window, marble mullions, with 28 square feet stained glass, at Rs. 698, ...	698
r. ft.		
14·5	Marble slab with inscription, at Rs. 3-12-4 per foot, ...	55
No.		
1	Polished marble font, at Rs. 121, ...	121
r. ft.		
11	Chancel rail, complete, at Rs. 17-5-4 per foot, ...	191
No.		
1	Iron finial, at Rs. 49, ...	49
4	Ornamental iron scrapers, at Rs. 12-9-10 each, ...	50
	Mats, chicks and curtains, ...	183
	Furniture (incomplete), ...	176
	Miscellaneous petty items, ...	726
	Total Rupees, ...	15,884

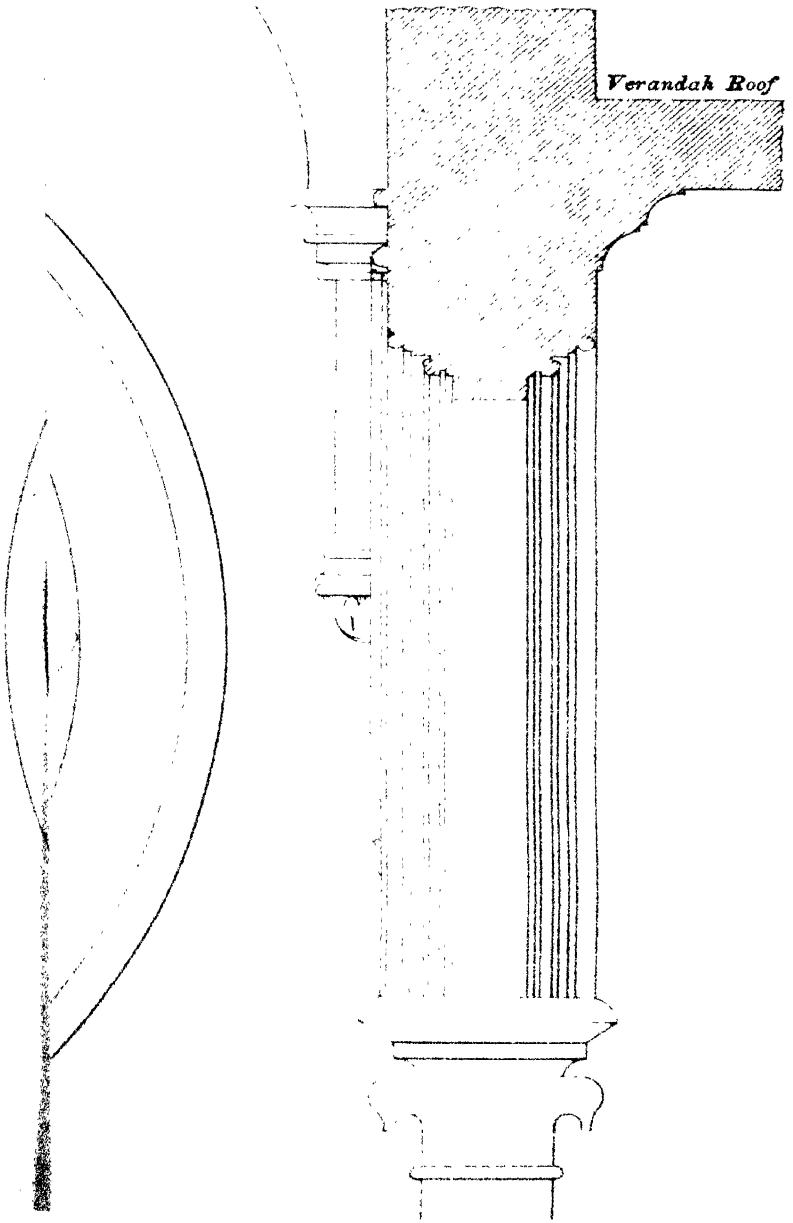
S. S. J.

UTANA.

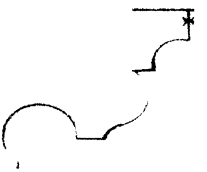



17
29'
13'6"
7'6"
11'
34'0"

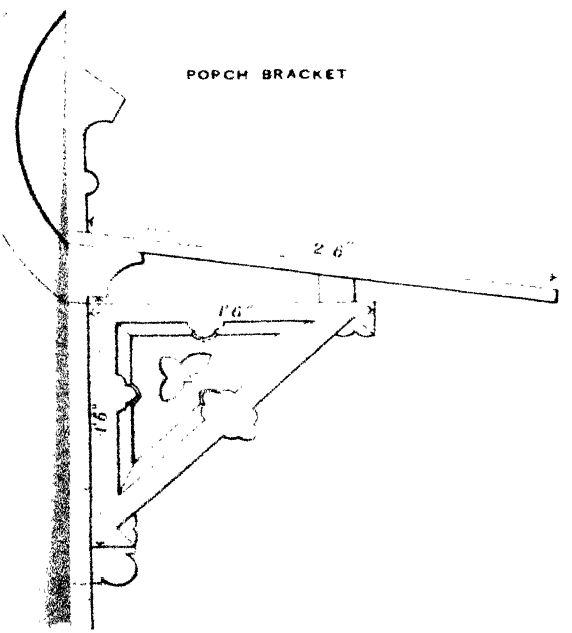
NAVE ARCH SECTION



BRACKET TO SUNSHADE



POPCH BRACKET



No. CCLXXI.

DISCHARGE FROM A TANK WITH CONSTANT SUPPLY.

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

[*Preface.*—This Problem has been proposed to the Author for solution from two different quarters at various times].

Problem.—A Tank receives a uniform supply, and discharges over a waste-weir with vertical cheeks. It is proposed to investigate—

i. At what height the water would be in a state of permanence over the weir.

ii. In what time it would attain a given height.

In the first place it is clear that until the water reached the level of the crest of the weir, there could be no Discharge from the Tank; and next that after it *began* to overflow, the Discharge would be at first very small, so that the head of water over the weir would constantly rise; the Discharge however would increase rapidly with the increasing head, whereas the Supply remains constant, so that finally the Discharge would just become equal to the Supply, and the water would then continue at constant level so long as the Supply was kept constant.

The questions proposed are:—

i. To find the height of this constant level.

ii. To find the time in which the water would attain any height less than the above.

From what precedes it is evident that the level of the crest of the weir is the most convenient plane for the zero of heights, and the time of attaining this level the most convenient "epoch" from which to measure the times.

Let t = time elapsed *in seconds* from instant of first overflow.

z = height of water-surface in tank above crest of weir *in feet* at time t.

A = horizontal sectional area of tank *in sq. ft.* at height z.

A_0 = horizontal sectional area of tank *in sq. ft.* at crest-level.

l = length of weir *in feet*.

q = supply of tank *in c. ft. per sec.* (supposed constant).

Q = discharge over weir *in c. ft. per sec.* under (variable) head z.

c = coefft. of contraction over weir.

g = measure of acceleration of gravity = 32 *nearly*.

In general, it is clear that Q, A are both functions of z, and therefore also of t.

By the ordinary formula for Discharge over Weirs, neglecting "velocity of approach",

$$Q = c \cdot lz \cdot \sqrt{2gz} = \tfrac{8}{5} clz^{\frac{3}{2}} \quad \ldots\ldots(1).$$

$$\therefore \frac{q-Q}{A} = \text{rate of elevation of water of tank } \textit{in feet per sec.}, \ldots\ldots(2).$$

Now, when this quantity is zero, it is clear that there will be "constant level", viz., when $q - Q = 0$, or $\tfrac{8}{5} clz^{\frac{3}{2}} = q$, *i. e.*, when

$$z = \left(\frac{q}{\tfrac{8}{5} cl}\right)^{\frac{2}{3}} = \tfrac{1}{4}\left(\frac{q}{cl}\right)^{\frac{2}{3}} \quad \ldots\ldots(3).$$

The preceding Problem (i) is simple enough: the remaining one (ii) is much more difficult. In fact the time in which the water attains a given height (less than the above of course) depends in an important manner on the *figure* of the tank. The actual steps of the solution which follows cannot be followed without a familiar knowledge of infinitesimals, but the principle is simple enough.

By the principles of infinitesimals it is clear that the "rate of elevation" of equation (2) is in fact $\frac{dz}{dt}$, so that

$$\frac{dz}{dt} = \frac{q-Q}{A}, \text{ whence } dt = \frac{A}{q-Q} \cdot dz, \quad \ldots\ldots(4).$$

Hence, since $t = 0$, when $z = 0$,

$$\therefore t = \int_0^t dt = \int_0^z \frac{A \cdot dz}{q-Q} \quad \ldots\ldots(5).$$

And since A is supposed to be a *known* function of z, and since Q is as a function of z by (1), this completes the *general* solution of the Problem. To make the solution take a definite form, it is only necessary to

assign the functional form of A (*i. e.*, the figure of the Tank). The only cases of interest appear to be—

CASE i. *Tank with vertical walls.*

CASE ii. *Tank with uniform side-slopes.*

CASE i. *Tank with vertical walls.* Here A is of course constant.

$$\therefore t = A\int_0^z \frac{dz}{q - 8\,cl\,z^{\frac{3}{2}}} \quad \ldots\ldots(6).$$

The integration is most conveniently effected by rationalization by writing $z = x^2$, which gives—

$$t = 2A\int_0^x \frac{x\,dx}{q - 8\,cl\,x^3}$$

the integral of which is given in Hirsch's Integral Tables, (Table XXXIX.)

as, $$t = \frac{A}{12\,kcl} \cdot \left\{ \tfrac{1}{2} \log_e \frac{(x+k)^3}{x^3 + k^3} - \sqrt{3} \cdot \tan^{-1} \frac{x\sqrt{3}}{2k - x} \right\}$$

or, $$t = \frac{A}{12\,k\,cl} \cdot \left\{ \tfrac{1}{2} \log_e \frac{(\sqrt{z}+k)^3}{z^{\frac{3}{2}} + k^3} - \sqrt{3} \cdot \tan^{-1} \frac{\sqrt{3z}}{2k - \sqrt{z}} \right\} \quad \ldots\ldots(7).$$

$$\text{where } k = -\tfrac{1}{2}\sqrt[3]{\frac{q}{cl}}, \quad \ldots\ldots(8).$$

which gives explicity the time t, in which the water level will attain the height z.

CASE ii. *Uniform side-slopes.* It is not difficult to see (by drawing a figure) that in this case the area A at height z is always expressible in form

$$A = A_0 + \alpha z + \beta z^2, \quad \ldots\ldots(9).$$

Thus taking an actual example, suppose the Tank rectangular in plan, and let

a_0, b_0 be the sides of cross-section A_0 at crest level.

a, b be the sides of cross-section A at height z.

i be the inclination of side slopes.

Then it is easy to see (by drawing a figure) that

$$a = a_0 + 2z \operatorname{cosec} i, \quad B = b_0 + 2z \operatorname{cosec} i$$

$$A = ab = a_0 b_0 + 2(a_0 + b_0)\, z \operatorname{cosec} i + 4z^2 \operatorname{cosec}^2 i, \quad \ldots\ldots(10).$$

which is obviously of form proposed (9).

Thus in general in the case of uniform side-slopes Eq. (5) becomes

$$t = \int_0^z \frac{A_0 + \alpha z + \beta z^2}{q - 8cl z^{\frac{3}{2}}}\, dz, \quad \ldots\ldots(11).$$

The integration is again to be effected by a prior rationalization by writing $z = x^2$, which gives

$$t = 2\int_0^x \frac{A_0 x + \alpha x^3 + \beta x^5}{q - 8cl x^3}\, dx$$

the integral of which may be taken from Hirsch's Integral Tables, Table XXXIX., and will be found to give after algebraic reduction, and paying attention to the limits, and substituting $x = \sqrt{z}$, as final result,

$$t = \frac{1}{24\,cl}\left(\frac{A_0}{k} + \alpha k\right)\log_e \frac{(\sqrt{z}+k)^3}{z^{\frac{3}{2}}+k^3} - \frac{\sqrt{3}}{12\,cl}\left(\frac{A_0}{k} - \alpha k\right)\tan^{-1}\frac{\sqrt{3z}}{2k-\sqrt{z}} -$$

$$- \frac{2}{3}\frac{\beta k^6}{q}\log_e\left(1 + \frac{z^{\frac{3}{2}}}{k^3}\right) - \frac{1}{4\,cl}\left(\alpha\sqrt{z} + \tfrac{1}{3}\beta z^{\frac{3}{2}}\right), \quad \ldots\ldots(13),$$

$$\text{where } k = -\tfrac{1}{2}\sqrt[3]{\frac{q}{cl}}, \text{ as before,} \quad \ldots\ldots(14).$$

which gives the time t in which the water level will attain the height z.

The most important time (t) to determine would appear to be that of attaining the "permanent level" given by Eq. (3). Now that Equation gives $\sqrt{z} = \frac{1}{2}\sqrt[3]{q \div cl} = -k$, and this renders *both* Results (7), (13) *infinite*, that is to say—

"Absolute permanent water-level will be attained only in an infinite time."....(15),

in both Cases i, ii. But further, on examining Eq. (5), this Result (15) is seen to be *generally* true, because the upper limit of the integral (which corresponds to the state of "permanent level") is defined by the condition $q - Q = 0$, so that the element function $A \div (q - Q)$ under the integral sign is in general infinite at the upper limit. This generally involves that the integral itself, *i.e.*, the value of t is also infinite, so that Result (15) is generally true, except when the area (A) changes in such a manner as to render the Result finite, an (exceptional case).

The explanation of this Result (15) is that the Discharge (Q) increases at first rapidly, but more slowly as it approaches equality with the Supply (q), and ultimately when nearly equal to q increases very slowly indeed, so that it can never become actually equal to the Supply in any finite time.

It may be remarked that this Result of a state of permanent motion being attained only after the lapse of an infinite time is the *ordinary* Result of all problems of retarded fluid motion.

It might also be proposed to ascertain the height (z), which the water level would attain in a given time t. The solution of this for the cases of a Tank with vertical walls or with uniform side-slopes is implicitly con-

tained in Results (7) and (13), but the equations are so complex that a numerical solution only could be obtained, and that only by a laborious approximation.

Practical Remark.—The solution here given is probably the best that can be given in the present state of Hydraulic Science. Its practical utility is however considerably diminished by the uncertainty in the present state of science as to the value of the "coefficient of contraction," (c). It is also hardly probable moreover that the "Supply" into a real Tank would be constant for any length of time, as proposed in the conditions of the Problem.

No. CCLXXII.

ON THE EFFECT OF USING A BRAKE SO AS TO PRODUCE "SKIDDING" OF THE WHEELS BRAKED OF A RAILWAY TRAIN.

By Capt. H. Wilberforce Clarke, R.E., *Offg. Depy. Consulting Engineer for Guaranteed Railways.*

The idea is popularly entertained that the retarding effect of a brake is not so great when the wheels are "skidded," as when they are permitted to rotate slowly.

This idea will be found in the "Roorkee Treatise of Civil Engineering," published in 1877, page 389, Vol. II., in the following form :—

In tire-brakes greater retardation is produced if the brakes are not pressed hard against the wheels, during the whole time required for stopping a train.

And, at a trial, which I lately attended—an Engine-driver of a Mail-train said :—

"When the brake was put on, the wheels skidded. The retarding effect is not so great then as when the wheels revolve."

From the Report of the Commissioners (Royal Commission on Railway Accidents 1877), Supplementary in Series, page 108, we have the information set forth in the following Table :—

No. of train, ...		1		2
Midland railway train, ...		Six vans.		Six vans.
Nature of brake used, ...		Hand-brake.		Hand-brake.
Weight in tons—				
Of train, ...	a	54·5	a	54·5
Resting on braked wheels, ...	b	54·5	b	54·5
Percentage of weight of train resting on braked wheels, ...	c	100	c	100
Number of wheels				
To which brakes were applied, ...	d	24	d	24
In train, ...	e	24	e	24
Time occupied in traversing last 800 feet, ..	f	13¾	f	13⅛
Speed at signal post—				
Miles per hour, ...	g	39·5	g	40
Feet per second, ...	h	58·18	h	58·72
Train stopped in—				
Feet, ...	i	679	i	577
Seconds, ...	k	19¼	k	17
Vis-vivâ in foot tons per second, ...	l	2864	l	2917
Mean retarding force—				
Tons, ...	m	4·22	m	5·06
Reckoned as percentage of gross load, ..	n	7·74	n	9·28
Friction of train in tons, ...	o	0·22	o	0·22
Mean retarding force produced by brakes—				
Tons, ...	p	4·0	p	4·84
Percentage of gross load, ...	q	7·34	q	8·88
State of rails, ...	r	Dry.*	r	Dry.†
Brakes how applied, :		Not with full force.		With full force so as to produce skidding.

It will be observed that, in consequence of a slight difference in the speed, the *vis-vivâ* of one train is not equal to the *vis-vivâ* of the other.

* One pair of wheels in two vans skidded at first, but were immediately released.

† One pair of wheels in the rear van, nearest centre were not skidded.

Column $c = \frac{a \times 100}{b}$

„ $l = \frac{\text{weight of train in tons} \times (\text{speed in feet per second})^2}{64{\cdot}4}$

„ $m = \frac{l}{i}$

„ $n = \frac{m \times 100}{a}$

Column $p = (m - o)$

„ $q = \frac{p \times 100}{a}$

To ascertain how far train No. 1 would have gone had its *vis-viv* been the same as that of No. 2, we have the following proportion:—

$$\begin{array}{cccccc} \text{Foot tons.} & & \text{Foot tons.} & & \text{Feet.} & \text{Feet.} \\ 2917 & : & 2864 & = & 577 & : x \end{array}$$

$$\therefore x = \frac{577 \times 2864}{2917} = 566{\cdot}5 \text{ feet.}$$

Hence the distance, a train, whose *vis-viva* is 2,864 foot tons, will go is:—

679 feet when the hand-brake is not fully applied.

566½ ditto ditto applied so as to produce skidding.

H. W. C.

1*st April*, 1878.

No. CCLXXIII.

ON THE CONSTRUCTION OF THE NARORA WORKS. HEAD OF THE LOWER GANGES CANAL.

[*Vide* Plates I. to XVI].

By Major H. Helsham Jones, R.E.

Before entering on the proper subject of this Paper it seems desirable to give a slight sketch of the history and general design of the Canal.

The (original) Ganges Canal, as most readers of this Paper are probably aware, was designed and constructed by Sir Proby Cautley of the Bengal Artillery. The famine of 1838 led to the project for its construction being taken up in 1839, when surveys were begun. Work was carried on slowly and with many interruptions, owing to wars and other causes, up to 1847 when the Government of India resolved that "the more vigorously the work can now be prosecuted, the cheaper it will be for the State." The canal was formally opened in 1854.

The Ganges Canal has its Head Works at Hardwar, nineteen miles above Roorkee, at the point where the Ganges issues through the Sewalik range into the plains. From thence it has a course of 350 miles to Cawnpore where its surplus water is given back to the parent stream. It throws off several branches which irrigate more or less thoroughly the country through which they pass. The red colour in *Plate* I. shows approximately the extent of country irrigated in 1876, which amounted to about 900,000 acres or 1400 square miles. This area however is considerably less than that which the projector of the Canal intended to irrigate and which the needs of the country demand. It was therefore necessary to supplement the supply.*

The Head of the Ganges Canal is situated so close to the hills that the

* The Ganges Canal has 618 miles of main canal and branches, and about 3360 miles of distributaries. Irrigation, generally speaking, extends one mile on each side of a distributary channel, or rajbuha. Consequently the canal commands about 6726 square miles. It irrigates about 20 per cent. of its field annually.

bed of the river there consists of large boulders. Consequently though all the apparent supply of the river may be drawn off a large quantity of water filters away unobserved, and can only be caught lower down where the bed is of a closer nature.

The Ganges Canal is, as above stated, 350 miles in length. It is evident that there must be considerable administrative difficulties in working a canal of such length extending through a long stretch of country from north to south passing through districts having various wants and different kinds of cultivation. Moreover there are no less than twelve "districts"* to be dealt with ruled over by twelve Collectors with their different ideas. With them as well as with the three Commissioners of Meerut, Agra, and Allahabad the Engineers in charge of the canal have to transact business. Then there is great loss by evaporation and percolation before water taken in at Hardwar can be used in irrigating at Etawah or Cawnpore, so that if water can be obtained by a shorter road, it is evidently desirable to relieve the works in the upper parts of the canal from the strain of carrying what is required for the irrigation of the lower districts.

The Lower Ganges Canal is intended to relieve the old Ganges Canal of the duty of irrigating the country in the lower part of its present field, to set free a large volume of water for use in the more complete irrigation of the upper part of that field and, by bringing in a supply of water drawn from the Ganges at a long distance below Hardwar,† to irrigate the country which it takes over from the old canal more economically than at present. Also to extend the irrigation of the Ganges-Jamna Doab as far down as the Allahabad District. *Plate* II. shows the Doab‡ as re-distributed for irrigation between the old and new canals. It is on the same scale as and may be compared with *Plate* I.

Since a dam situated many miles below Hardwar will give the head required for commanding the lower Doab and will intercept water which escapes the Hardwar dam, as well as a considerable volume received by

* An Indian Civil District is as large as many English counties [illegible] managed by a civil officer styled Magistrate and Collector. Three or four such districts form a Division which is superintended by a Commissioner.

† Hardwar to Narora, by the river, about 150 miles.

‡ Doab. This is a useful Persian word which has no English equivalent. Derivation, *Do*, two; *Áb*, water. It means the whole tract of country between two rivers. The Ganges-Jamna doab is known as "The Doab." In the Panjab the doabs are named by combining the consonants of the names of the two rivers. Thus the Rachna doab is that between Ravi and Chenab: the Jach doab between Chenab and Jhélam.

the river in its downward course, it is possible to attain the object in view without very largely reducing the allowance of water to be taken in at Hardwar. The Ganges Canal usually takes in from 5300 to 6000 cubic feet per second in the cold season. This amount is to be reduced by 750 to 1000 cubic feet. Under this arrangement it is expected that from 3000 to 3500 cubic feet per second will be obtainable at the new canal head in the cold season. For purposes of navigation the old canal must keep up a supply of 750 to 1000 cubic feet in the Cawnpore branch. This will pass on to the new canal and bring up the cold weather supply to from 3750 to 4500 cubic feet per second.*

The Lower Ganges Canal is intended, like the older canal, to provide for navigation as well as for irrigation, but of course the former will be subordinate to the latter. As the velocities of the new canal will be much lower than those of the old one, even as now moderated, the conditions are so far more favourable. The interests of irrigation and navigation are so essentially divergent† that no very great amount of traffic can be hoped for. The Lower Ganges Canal in combination with the old canal will give water communication between Hardwar and Allahabad and thence to Calcutta by the river

The Committee of which Colonel E. Lawford R.E. (Madras) was president, which reported on the Ganges Canal in 1866, notices Rajghat as a possible sight for the Head-Works of a canal for supplementing the irrigation of the Ganges Canal and for supplying additional water for the lower part of the Doab. That Committee formed a rough design and estimate for the Weir and an estimation of the cost of the canal amounting altogether to nineteen millions of rupees. They concluded that "the project may be worthy of more careful examination at some future period."

The project was first taken up in earnest in the year 1869. The site for the Head Works was then, after careful survey, fixed at Narora. This place is four miles below the Ganges Bridge of the Oudh and Rohilkhand Railway at Rajghat and the same distance above Ramghat, where

* The lowest discharges registered at Narora has been 1630 cubic feet in May 1873, and 1569 cubic feet in February 1870. The discharge is usually not below 2200 cubic feet while the Ganges Canal is running a full supply.

† Take, for example, the single item of alignment To be successful a navigable canal should connect the large towns of a district with the capital. Whereas the first condition of an irrigation canal is that it must keep on the main watershed of the country The Ganges Canal does not touch one of the large towns between Hardwar and Cawnpore

the old road from Aligarh to Bareilly crosses the Ganges. It is in the Bulandshahar District and 30 miles from Aligarh by road. (The Rajghat station of the Oudh and Rohilkhand Railway is also 30 miles from Aligarh.)

The year 1870 was spent in perfecting the surveys and in making designs, and 1871 in lining out, search for material, &c. &c. The Narora Division was formed early in 1872. In October of that year brick-making was begun, some houses were built and the Workshop buildings, which it was important to have ready and fitted up as early as possible, were begun. As it turned out these were not begun soon enough, nor did the machinery, which had to be obtained by a cumbrous system of indenting on England, arrive early enough, and the result was that the Workshops could not be organized before the first working season (that of 1873-74). This caused considerable delays to the work.

The Workshops were formed into a separate Division; an arrangement which it is not desirable to imitate elsewhere, as it leads to a great deal of additional correspondence and accounting and to a division of responsibility.

At the beginning of 1873 about 90,000 bricks had been made, houses to shelter a small establishment were ready and the Workshop buildings were fairly advanced. No machinery had yet arrived from England. A small quantity of timber and some block kankar had been collected. It was at this stage that the present writer took charge of the works in March 1873. Before proceeding to the arrangements made for the execution of the works it will be well to describe generally;

I.—The nature of the site.

II.—The character and dimensions of the Works to be constructed.

III.—The materials available, and the style in which the works were to be carried out.

I. The nature of the site.

Plate III., *Fig.* 1, shows generally the state of the site at the time the work was first laid out. The crest line of the weir was laid at right angles to a line joining the right abutment of the Rajghat Railway Bridge, with the right flank of the works. This was fixed at a point withdrawn about 30 feet from the actual bank of the river near the little hamlet of Jairampur* and about 4,000 feet below the village of

* Jairampur has since been removed to a new site.

Narora. The high bank which in all places bounds the Ganges Khadir on the right, and which (*see Plate* III.) runs tolerably straight from Rajghat to this point, here bends to the westward while the river continues in a nearly southerly course to Ramghat, leaving a strip of low land to its right.

By placing the weir in the position chosen it became possible to carry the canal along this strip of low ground (or khadir land) as far as Ramghat, thus avoiding four miles of heavy excavation. The average elevation of the high ground near the river above low water level is about 36 feet. The canal channel, as will be seen on *Plate* III., *Figs.* 3 to 6, is carried along just below the edge of the high ground. It may seem that this is a dangerous position but, owing to the curious fact that the slope of the country is westward away from the river, very little drainage passes into the khadir on this part of the line. It is only where the vertical face is broken by ravines which have cut back that any drainage surface water flows into the khadir. Advantage was taken of this peculiarity in forming the station river face slopes at Narora. The ravines were filled up with spoil, the slope turfed, and an edging one foot high run along the crest of the slope to prevent cutting. The drainage of the station then all flowed westward away from the edge of the high ground.

In April 1873 when the works were laid out the actual river bed occupied little more than half of the whole width allowed for the Weir and Sluices viz. about 2400 feet out of 4135 feet. This left 1730 feet the whole of which was khadir land above the level of any but the highest floods. The odd 30 feet only lay on the right (or west) bank and the rest on the left.

The bed of the river, as described by Col. Lawford, consists of remarkably fine micaceous sand totally unlike that of the Madras rivers. It sinks when wet under the slightest pressure. The high bank on the right is formed of coarser red sand with a slight mixture of clay and is supported by some beds of clay. The headland of Ramghat is very strong and has some beds of kankar in it, but this is by no means the case everywhere. A great deal of the village of Narora has been washed away in comparatively recent floods.

The left bank is low and consists of merely the same sand as the bed with a few thin layers of alluvial soil in it and has no power to resist the action of the river when directed forcibly on it. The actual boundary of

the Ganges valley or khadir is distant on this side from 12 to 14 miles, (see *Plate* IV.) The section is very peculiar and demands certain precautions which will be referred to later.

The light silt of the river is of course liable to be very deeply scoured out in floods, but it was believed that a bed of clay which had been found to exist at a pretty uniform depth of about 30 feet below L. W. M. at the Rajghat bridge from bank to bank would be met with here also. This was subsequently found to be the case

II.—The character and dimensions of the works to be constructed.

Plate V. is a general plan of the works, which consist of—

(*a.*) A weir 3800 feet in clear length between the abutments. This is known as "The Weir Proper". It is supported on its left flank by a work known as the Left Wing Wall which extends 242 feet up- and down-stream. On its right flank it rests on the Weir Sluices.

(*b*). A set of sluices on the right bank adjoining the Weir. These sluices are 42 in number, each opening being 7 feet 3 inches in clear width with piers of 2 feet 9 inches. This work is known as "The Weir Sluices" and is 444 feet in length including its abutments. It stands in prolongation of the Weir Proper.

(*c.*) Forming by its face line an angle of 105° with the crest line of the Weir lies, on the right bank, "The Canal Head". This work stands on a floor 50 feet wide and is connected with the Weir Sluices by a revetment wall 30 feet long. It contains 30 sluices of 7 feet clear opening for admitting and regulating the canal supply. The total width of this work between abutments is 282 feet 6 inches. The canal revetments springing from it are slightly convergent and at 250 feet from the face line, the regular channel of the canal begins on a curve of 3100 increasing to 4300 feet radius with a bottom width of 211 feet and side slopes of $\frac{1}{2}$ to 1.

At a distance of 751 feet up-stream of the crest line of Weir is the entrance to the Lock. Its axis makes an angle of 30° with a normal to the crest line and is set back 110 feet from the normal at point O (see *Plate* V.) It is connected with the Canal Head by a curved wall 401½ feet in length, called the River Wall.

The Lock is 20 feet wide at bottom, and has a clear length of 150 feet between the gates. The right wall of the head bay is continued 78 feet up-stream in continuation of the River Wall allignment and ends

with a return of 43½ feet into the bank. On this return wall rests a puddled clay bank with a kankar facing which is carried 1000 feet up-stream to the Narora Inspection House. This supports a turfed slope and protects a road which descends at a gradient of one in forty from the Inspection House to the Lock. This completes the works on the right bank of the river, the natural high bank being of course the best possible *point*

On the left bank however the case is different. Reference has been already made to the peculiar cross section of the Ganges Valley at Narora, which is very clearly shown by the section on *Plate* IV.

In raising by means of a weir the natural flood level of a river there is always the danger of an overflow to be guarded against, where the banks are low. Should a high flood get round either flank it of course returns with great force to the stream and when, as is the case with the rivers of the Doab, the soil is only fine sand, great precautions are necessary to prevent the formation round the flank of the Weir of a deep channel which it would be difficult and costly to close.* The left flank of the Narora Weir would therefore *in any case* require very careful protection. But the section points to another danger, inasmuch as the Ganges at the present time does not run in the lowest part of its own valley but in a comparatively high level bed on the western edge of it. There is therefore the necessity of guarding with special care against any tendency to spill to the East.

Accordingly an embankment 15 feet wide at the top and designed 3 feet above the highest possible flood has been carried from a point 1000 feet East of the Left Wing up to the embankment of the Oudh and Rohilkhand Railway opposite Rajghat (a distance of four miles) and this longitudinal embankment has been strongly protected by three groynes at right angles to it projected into the river. The longest of these groynes is 4600 feet in length and the shortest 2400 feet (see *Plate* III., *Fig.* 6.) As the construction and action on the river of these works has been described in a recent paper (No. CCXXXIV.) no further mention of them will be made in the present.

The following are some of the principal levels reduced to the Great Trigonometrical Survey datum of Mean Sea :—

* A case of this kind occurred at Okhla in 1871 and is described in No. CXXVI of these Vol. III., Second Series.

	R. L.
L. W. M. of Ganges in its normal state, (or "Summer Level"),	575·00
H. W. M. Bed of, „ „ „ ..	569·00
(or Highest Flood), „ „ „ ..	588·00
H. W. M. above Weir when complete (calculated), ...	590·00
Level of Weir Floor (surface), ...	572·00
„ Crest of Weir, ...	581·75
„ Canal, (sill of Head Sluices,)	575·00
„ Floor Weir Sluices, ...	572·00
„ up-stream Platform of Weir Sluices and of top of all revetments of the Crest Line of Weir, ...	593·00

Plates VI. to X. show the works in detail.

The Left Wing wall (*Plates* VI. and VII.) is an ordinary revetment on well foundations.

The Weir Proper (see *Plate* VIII.) consists of a wall 8 feet thick at base and 9 feet 9 inches high standing on a line of blocks. The water falling over this wall will descend upon a floor 40 feet wide and 5 feet thick. The down-stream edge of the floor is supported by a line of eight-feet wells sunk to 20 feet below L. W. M. and having the intervals very carefully piled. An apron up- and talus down-stream, formed of heavy material, complete the section.

The Weir Sluices (*Plates* VII. and IX.) form a double-storied building standing on an ashlar floor 427 feet long and 155 feet wide. The floor is 1 foot thick with 4 feet of brickwork and concrete under it. The entire area of the foundation is enclosed by wells. The part of the foundations under the superstructure is entirely composed of blocks in four lines, and other lines of blocks break up the rest of the area into compartments of a size manageable for pumping and concreting. The Canal Head (*Plates* VII. and X.) stands on a floor 282 feet 6 inches long by 50 wide. The foundation area is broken up like that of the last-mentioned work but as the superstructure is lighter there are no blocks under it. The whole foundation is composed of concrete rammed into the compartments formed by the blocks. The construction of the River Wall and Lock is similar, the former standing on 12 feet wells and the latter on block foundations.

A part of the wells are sunk down into the clay bed. These are the wells under the Left Wing, those under both abutments of the Weir Sluices and the line of wells supporting the lower edge of the ashlar floor of the Sluices. In addtion to these the wells in the Weir Proper for a length of 500 feet measured from the Weir Sluices (see *Plate* VI.) are sunk into

the clay, instead of to 20 feet below summer level only. The object of this is to secure the Weir against the scour of water issuing from the Sluices and possibly rushing towards the left to find its way into some deep channel of the river below the Weir.

The blocks on the up-stream side of the Weir Sluices are sunk to 18 feet below L. W. M. (or R. L. 557). Those in front of the Canal Head and under the River Wall to 15 feet (R. L. 560). Blocks within the works to less depths, generally to R. L. 565 or 10 feet below L. W. M. As the river is liable to considerable fluctuations even in the cold weather the above figures do not by any means represent the whole of the work to be done. Many kerbs were laid much above the nominal Low Water level.

The numbers of wells and blocks in the works are as follows :—

Left Wing, ...	27 wells.		
Weir, ...	422 wells and 234 blocks.		
Weir Sluices, ...	86 „ „	232	„
Canal Head, ...	2 „ „	63	„
River Wall, ...	47 „		
Lock, ...	3 „ „	66	„
Totals, ..	587 „ „	595	„

The total sinking to be done was 14,220 feet in wells and 12,947 feet in blocks. Of this the most difficult part was the sinking of those wells which went to clay. There were 169 of these.

Appendix A gives the quantities of the works.

The principal items are—

Brickwork, ...	2,056,000 cubic feet.
Concrete, ...	1,287,000 „
Ashlar, ...	302,200 „
Block kankar, ...	2,508,000 „

besides about 1,000,000 cubic feet for temporary protective works.

This amount of brickwork would require about 30 millions of bricks and 800,000 cubic feet of lime. In addition there were other works in the vicinity to be provided for. The concrete would require about 1,100,000 cubic feet of ballast and 550,000 cubic feet of lime. There were therefore altogether about 1,350,000 cubic feet of lime to be provided for the Weir works.

The design of the Weir Proper was naturally the subject of the most anxious and careful consideration. The other works do not present any very special or unusual conditions, but the Weir was the first of its kind

that had been projected on any of the rivers of the Ganges class. The construction of the Okhla Weir, on the Jamna just below Delhi, could not be copied because the conditions are essentially different. At Okhla the right flank of the works rests on rock, and stone could be quarried to any extent required within a mile of the works, and at a very cheap rate. When placed in position in the work the cost per hundred cubic feet did not amount to Rs. 8.

At Narora no such facilities existed. No material whatever was to be found near the works and block kankar, the only substitute for stone which was obtainable, had to be brought from a distance and could not be placed in the work at less than Rs. 15 per hundred. Thus, besides that it is an inferior material, the cost of the block kankar and the difficulty of collecting and storing it in sufficient quantity caused any idea of imitating the construction of the Okhla weir to be rejected.

Were it possible to obtain wrought-iron in India at a moderate cost there is no doubt that Wrought-Iron cylinders or caissons would have been proposed, on account of the ease and regularity with which they are sunk and their other advantages. But the cost of wrought-iron was prohibitory and hence the designers had to fall back on the time honoured Indian method of sinking brick wells.

The Madras Weirs do not serve as patterns for construction in Northern India because the nature of the bed and general conditions are quite different. The same remark applies to the Weir for the Sone canals at Dehri which was constructed just before that at Narora. The sand of the river bed at Dehri is coarse gravel compared with that found in the Ganges bed at Narora.

The level of the Weir crest was fixed by the requirements of the canal supply (at R. L. 582),* leaving the length of the Weir, as well as its design in section a matter for discussion. Working from a maximum discharge of 200,000 cubic feet per second, the Weir was designed by Major Jeffreys with a length of 4,000 feet in the clear between the Left Wing wall and the Left Abutment wall of the Weir Sluices.

The water is to be raised 7 feet in cold weather above its former level and it was calculated that the obstruction caused by the Weir would lead to an afflux of two feet in highest floods, increasing the H. W. level from 588 to 590, and giving a velocity over the Weir of somewhat over 10 feet.

A proposal to reduce the length of the Weir to 3,000 feet was made, but was ultimately withdrawn, by the Government of India. In the course of the discussion Lieut.-Col. Brownlow showed, from observations on the Jamna at the Okhla Weir during the floods of 1871, that in the neighbouring basin of the Ganges, a similar rainfall might give 230,000 cubic feet per second of discharge at Narora. Though the floods of 1871 were heavy there is no reason to believe that they were the highest that have occurred, and therefore it is not unreasonable to expect that 300,000 cubic feet per second, which was the maximum discharge as estimated by General Lawford's Committee, may at some time have to be passed.

The formula used for calculating the discharge over the Weir was that for submerged weirs viz.:

$$Q = 3{\cdot}5\, l\, h_1 \sqrt{h_1 + 0{\cdot}035\, u^2} + 5\, l\, h_2 \sqrt{h_1 + 0{\cdot}02\, u^2}$$

where l = length of weir, u = velocity of approach (taken at 6 feet per second), and h_1 and h_2, as shown in the diagram.



With regard to the section of the weir, the form, with a vertical drop and an ashlar floor to withstand the action of the falling water, was dictated by the circumstances of the case, which required economy of material. The foundations were however a matter open for discussion.

A systems of iron screw piles with grooves in them placed at short intervals in a double row to receive a sheeting of wrought-iron was proposed by Lieut.-Col. Brownlow in December 1869. Major Jeffreys in the designs worked out in 1870, abandoned this in favour of square blocks sunk at intervals to support lengths of double sheet piling. Between the sheeting the sand was to have been cleared out and the space filled with solid concrete.

Both plans are open to the objection that a great amount of pumping power would be required to lay the interior dry, and keep it so while concreting was done. The second plan would have probably been found

impracticable, on account of the irregular sinking of the blocks. It is impossible to sink brickwork wells, and still more blocks, so as to ensure their being perfectly plumb, and therefore openings would constantly occur where the piling adjoined the brickwork. And these openings it would be difficult or even impossible to close.

In the design made in 1872 wells were substituted for blocks in the deeper line of foundations, and it was decided to close the intervals between the wells by means of solid piles.

The depth to which the wells should be sunk was much discussed. The first design showed them 16 feet below L. W. M., or at R. L. 559. That of 1872 carried them to 20 feet, or R. L. 555. Lieut.-Col. Brownlow however advocated carrying them to the clay, which lies at about 544, or 30 feet below L. W. M. in order to afford thorough protection against the scour of floods. A proposal was made on the review of the plans in the Government of India Secretariat to reduce Major Jeffrey's 20 feet to 10 only, on the ground that a deep substructure is not required to prevent leakage under the work. It was urged that the river bed would silt up to the level of the weir crest, and that the deposit of clayey layers of silt would puddle the work. To this it was replied that such deposits of silt occur in falling floods, and that they are swept out again by the full current of each high flood. This view, it may be remarked, has been since strongly confirmed by the fall of a jetty which projected up-stream from the Okhla weir. The supports of this jetty rested on the sand about 5 feet below the level of the weir crest and were protected by stone pitching. Notwithstanding this they were washed out in the floods of 1876 and the jetty ruined.

Ultimately the proposal to diminish the depths of foundation was withdrawn and permission given to sink into the clay the wells extending over a length of 500 feet from the Weir Sluices. Those on the other part of the work were to go to R. L. 555 only, or 20 feet below L. W. M.

The level at which the ashlar floor should be laid was a good deal discussed, and a proposal made to fix it at R. L. 575, or the level of L. W. M., in order to save pumping. This however was ultimately withdrawn and R. L. 572 approved of. It is placed below the old cold water surface level on account of the retrogression of levels which may be expected when the Weir is finished.

III.—*The materials available, and the style in which the works were to be carried out.*

The actual neighbourhood of the works afforded no material besides brick earth. Fortunately this was found, in very fair quality and ample quantity, about two miles from the Weir. A contract had been made in 1873 with an excellent firm of European Contractors who were already in full operation in March 1873, and there was no ground to apprehend any failing of the supply of bricks, although wood fuel for the flame kilns had to be brought from long distances. Coal was tried in 1873, but with indifferent results. The vicinity of the Oudh and Rohilkhand Railway and the branch line to Narora (which will be noticed presently) rendered the supply of fuel from a distance perfectly feasible and a question of cost only. From beginning to end of the works the supply of bricks has kept pace with the demand. In addition to the brickfield at Narora (the position of which is shown on *Plate* XI.) a smaller one was established at Ganaur, on the left bank of the Ganges and about 4 miles from the Left Wing. This was useful in the earlier stage of the work before the tramroad could be carried across the river from the right bank.

Lime.—The supply of Lime seemed at first to present some difficulty as it would have been very tedious and costly to collect so large a quantity from a number of scattered quarries by means of carts. Fortunately the kankar fields near a village called Bilon which lies close to the railway promised on a careful survey to yield a very large quantity and in the end all other sources of supply were abandoned, owing to the convenience which the railway offered for prompt and orderly delivery. The material was delivered, by the contractor for digging and cleaning it, in stacks along the line and was brought in by train loads as required. Kankar being (as is well known) of very various character in various places it was a great advantage to draw the supply from one place. The distance by railway is 14 miles from the stacking grounds on the line to those at Narora. Each train of 30 wagons carried 5,000 feet, and made two and sometimes three trips in a day.

Like the lime kankar, the supply of block kankar was at first a source of some anxiety. No other alternative material for pitching was obtainable. Stone for instance cannot be thought of, the nearest source of supply being beyond Delhi, or beyond Agra.

Numerous quarries were examined and small supplies obtained, some

of them 20 miles distant by road. Finally it was ascertained that the quarries North-east of Aligarh lying near the Oudh and Rohilkhand Railway would supply all the needs of the work, and stacking grounds were established along the line between Aligarh and Hardwaganj from which the supply was worked in by train loads in the same way as the lime kankar. The distance by rail was about 32 miles and the material had to be carted from 3 to 6 miles to the line.

The large mass of ballast required for concrete was another want which required early attention. The usual sources of supply, such as refuse of brick kilns &c., were speedily exhausted when so large a quantity was required. Nodular kankar makes only indifferent concrete and the supply of that was not abundant. Of course all the vitrified or misshapen bricks were broken up but the great mass of the supply consisted of small cubes of clay specially made and burnt in clamps with *upla*. There was a good deal of trouble at first in getting this properly burnt but ultimately very good material was obtained. The clay was spread on a floor to a thickness of about an inch and cut up with knives to the size required.

For ashlar several sources of supply were available. The quarries near Mirzapur, on the East Indian Railway are well known and have been long in work.

They supply a hard close grained sandstone of a pinkish-gray colour which resists well the action of water but is rather brittle. This has to be brought over 400 miles by railway to reach Narora and is therefore rather costly. Its price was Rs. 1-10 per cubic foot delivered at Narora in blocks of 5 feet by $2\frac{1}{2}$ and 12 inches thick dressed ready to set in a floor.

The quarries in the Bhartpur State near Agra offered the well known red and yellowish-white varieties of sandstone at Rs. 1-4 and Rs. 1-9 per cubic foot respectively. Delhi quartzite could have been had, but was rejected owing to the great difficulty of getting it properly dressed.

The greater part of the floors were laid of Mirzapur and yellow Agra stone. A small quantity of red Agra was used.

A very fine stone has been used for the cutwaters, quoins and coping of the works. It is a metamorphic sandstone from quarries in the Alwar State near Malakhera Station on the Rajputana State Railway. It is of a very handsome gray colour and is very hard, but not too difficult to dress. Unfortunately the quarries have never been systematically

worked and therefore it is not possible to make sure of a very large supply of this stone being promptly delivered.

This stone is similar to some found near Gwalior which has been largely worked and there is no doubt that when the Gwalior Railway is opened it will be possible to obtain most excellent stone for hydraulic works from Gwalior at a moderate cost. The stone from Malakhera cost Rs. 1-8 per cubic foot ready dressed and delivered as above. As the quarries are none of them in the habit of turning out very large quantities of stone it was necessary to begin getting in the supply very early.

It was intended to execute the work with the exception of the upper part of the Weir Wall, and the upper storey of the Sluices in three working seasons, viz., 1873-74, 1874-75, 1875-76. To accomplish this it was necessary to make use of means not usually employed in India. The supply of materials of all sorts was to be effected by tramways, steam machinery of all kinds was to be used in the shops, steam mills for grinding lime on the works and a liberal provision of steam pumps hoists &c. was made for the works.

It was very fortunate that the Canal Works lay within a short distance of the Oudh and Rohilkhand Railway. This Line was only opened a short time before the canal works were began. But for its aid the Narora works would been required a much longer time to complete, the collection of materials on the spot must have been much more extensive, and the works would have proved much more costly. As it was, the construction of a short branch line of four miles from the Rajghat Station of the Oudh and Rohilkhand Railway to Narora not only rendered this very large collection of materials unnecessary but also rendered it possible to utilize the rolling stock of the company to a large extent in the actual execution of the work.

Plate XI. shows the method of laying out the station with the tramways, stacking field, mortar factory &c. &c. The object kept in view was to arrange everything so that all preparation of material might be completed at a distance from the works and that everything when brought down should be used up day by day. The first idea had been to use the metre gauge on the works and in the station, but this was abandoned in April 1873 in favour of a uniform broad gauge which allowed the Oudh and Rohilkhand Railway stock to work upon any part of the Canal lines. The four mile length from Rajghat to Narora station, though constructed by the Canal Engineers, was made over to the Com-

pany and worked as a Branch Line, the Company having its own officials at Narora Station. The rest of the lines were worked by the Canal Engineers, the Canal Station being close to the Weir Sluices, (see *Plate* XI.) and connected by telegraph with Narora Station. A branch was carried into the Workshops. These are off the main line, their position having been fixed when a metre guage line was contemplated, but no practical inconvenience has resulted from this and their position relatively to the Weir works is very convenient. These Shops being a separate charge the want of some small shops under the immediate control of the Engineers in charge of the Works was soon felt and such shops were constructed close to the Weir Sluices as shown in *Plate* XI.

The usual railway rules were enforced on the canal lines and only two accidents have occurred in working for three-and-a-half years. The wagons used, 104 in number, were purchased from the Bombay Reclamation Works and are of teak. They measure inside 8 feet by 7 feet by 1 foot 5 inches * and therefore hold 96 cubic feet. Three locomotives (tank engines) were purchased from the Oudh and Rohilkhand Railway Company.

The permanent way consists of 35 lb. rails purchased from the Oudh and Rohilkhand Railway Company. It is called Wilson's from the Engineer of the company who designed the peculiar sleepers, which consist of two plates of corrugated iron connected by a tie-rod. On the incline into the khadir and on the works wooden sleepers were used. The Wilson sleepers are laid on a bed of kankar consolidated by ramming.

A considerable reserve of block kankar has been kept up at Narora but, as a rule, the material has been worked in from the various points of delivery on the railway direct to the works. The supply at Narora is kept in long narrow stacks *parallel* to the lines. This arrangement facilitates the stock keeping. Each stack contains 12,000 cubic feet and can be worked off in about four train-loads. The bricks are kept in the same way in stacks of 125,000 each; equal to three train-loads.

Ashlar yards.—Though the stone was contracted for dressed ready to set in the work there is always a little work to be done to make a perfect fit. The floors were all laid out and fitted up on the stacking ground precisely as they were to lie in the actual work. Each line of stones was numbered and the stones had each its own number also. These numbers were painted on the stone and diagrams showing the position of

* Some were smaller 7 feet by 7 feet 2 inches by 1 foot 4 inches holding 67 cubic feet only.

each stone in the floors prepared. The Officer in charge of the works indented daily, by number, for the blocks he required. The stones were picked out by gangs of porters (*bandhānis*) and carried to the cranes which loaded them into wagons. This was always done at night for the next day. Each stone has a lewis-hole for lifting it.*

Mortar Factory &c.—Plate XI. shows the position of the mortar factories, lime kilns, and depôt for lime kankar. The mortar used was composed of two parts of ground lime and one of red sand, measured dry. The sand used is a fine red granular sand found on the site of the works. It was carefully washed in small wooden vats. Careful experiments on the available limes were made (begun by Mr. M. King, Personal Assistant to the Superintending Engineer) before the proportions were decided on, and they have been continued up to the present time: Samples being frequently taken from the mortar mills, made into dumb-bell shaped briquettes and tested by Adie's machine for tensile and transverse strength. In order to obtain the transverse strength a little addition was made to Adie's machine. A stirrup was attached in the place of the upper clip having a knife edge on its lower part. The prism to be broken was held down by two clips to the bed of the machine. These clips were arranged so as to give a clear bearing of 4 inches and the knife edge being adjusted at the centre of the prism the strain was put on in the usual way and the prism broken upwards.

Plate XII. shows the sort of kiln used, which is identical with those used by Mr. R. J. Mallet at the Ravi bridge of the Punjab Northern State Railway. Mr. Mallet however used charcoal and obtained an out-turn of 40 cubic feet per diem from each chamber only. At Narora the fuel used is a mixture of coal and coke, and 100 cubic feet per diem have been obtained regularly. Both coal and coke are pounded fine, and are mixed in the proportion of two parts of coke to one of coal by bulk. It is found that about 9 cubic feet of fuel are required to 100 cubic feet of kankar measured when put into the kiln. The kankar is broken to the size of a walnut and thrown in by baskets. The fuel is kept in a tub on the top of the kiln and scattered over the kankar with a small tin scoop. By practice the workmen soon learn to

* The Agra and Mirzapur stones are found to require a very deep and slightly tapered lewis; those finally used are 6 inches deep and 3 inches wide at neck and 3½ inches at base. They are 1½ inches thick.

judge the proper quantity. Out of 1,530,000 cubic feet of kankar burnt at Narora to the end of March 1877 only a few thousand cubic feet of refuse has been lost. Six kilns were constructed on the right bank and three at the left wing; capable of giving altogether an out-turn of about 3600 cubic feet per diem. This was rather in excess of requirements, as the steam mills, when all were completed in cold weather of 1874, could grind only 2600 cubic feet per diem. The reason was the great increase of out-turn obtained with the more powerful fuel over and above what was first expected. The lime is slaked and ground in steam mills.

The mills in use on the right bank are four nine-foot pans with direct acting engines of 8 horse-power, two seven-foot pans mounted together and driven by an 8 horse-power portable engine, and one eight-foot pan driven by a 10 horse-power portable.

Three six-foot pans mounted together and driven by a 10 horse-power portable engine are used on the left bank of the river. There was no perceptible difference in the lime ground by the different mills, though it might have been expected that the heavier the roller the finer the powder. The most economical of the mills are the six-foot trio.* The pair of seven-foot comes next, and the large pans with direct action are the least economical of all. As far as possible mortar has been made from fresh lime but this has not been always feasible. For concrete all the lime had to be ground and stored in bags. So long as it is kept dry the kankar lime does not deteriorate from being kept a moderate time.

The daily out-turn of mortar with all the mills in full work is 600 cubic feet on the left and 2000 cubic feet on the right bank; but it would not have been safe to expect this always, as stoppages were not unfrequent owing to the liability of this class of machinery to get out of repair.

The Narora Workshops.—The position of the Workshops (*see Plate* XI.) has already been referred to when describing the arrangement of the station. Their lying off the main line of tramway proved in working a convenient arrangement as the traffic for the shops was thereby kept distinct from the rest.

Plates XIII. and XIV. show the arrangements of the shops, the latter showing in detail the position of the various machines. The buildings

* Consumption of fuel to 100 cubic feet of mortar turned out —
With the three 6-foot pans 4 maunds or 329 lbs.
„ two 7 „ 5 „ „ 411¼ „
single 9 „ 12 „ „ 987 „

consist of two long shops of which the Eastern is the Smithy and Pattern-shops. It contains 26 fires blown by an American blower. When work was at its height there were also 25 temporary fires outside on the East. The North end of this building is the pattern room. The West shop contains at the South end the Foreman's office, then the fitting and iron construction shop, next the wood machinery and in an annex at the North end a vertical saw-mill. The nature and number of the different machines will be seen on inspecting the plan. A small steam-hammer would have added greatly to the resources of the shop. One was put up in 1877.

On the West side of the West shop is a large plaster platform for "constructing" work. Further West, laid out parallel to the buildings, are four temporary sheds 200 feet long by 20 wide for carpenters and joiners. The timber and other stores were disposed in different parts of the enclosure, tools and other valuable articles being stored in a store-house on the East side of the shops and the sawn timber in sheds along part of the enclosure wall.

At the South-east angle a part of the yard was partioned off as a store yard for the Weir Division. All materials for that Division were delivered there and stored until actually required on the works. The Executive Engineer of the Workshops was also charged with the care of all the engines and machines employed on the works. The locomotives running on the canal tramways were kept in the yard and came in to shed every evening. During the day they generally took in fuel and water in the khadir, where a tank was put up for the purpose.

These Workshops had to supply not only the needs of the Weir works but also of the Ramghat cutting, a large work belonging to the Weir Division in which three locomotives and a large number of wagons were running; also those of the lower Divisions of the canal. All this naturally entailed a great amount of work and kept the establishment and a large number of workmen fully employed. All the wagons for Ramghat were made in the shops. Those belonging to the Narora tramways though purchased in Bombay have required very extensive repairs and even reconstruction during the 3½ years they have been in constant use. The iron gates for the Sluices and Canal Head (42 of the former 7½ feet wide by 13 feet deep, and 30 of the latter only a trifle smaller) were a heavy job. Driven as the engines were against time for months together,

the renewal of the working parts of locomotive and portable engines and of steam pumps and mortar mills gave constant work.

Timbering and fittings for a large number of canal bangalows was another heavy job; but it would be almost impossible to enumerate the various requirements which were efficiently met by the Workshops and it must suffice to say that without their aid and the hearty co-operation of those in charge of them it would have been impossible to carry on the works. The cost of the buildings and plant was Rs. 1,36,000.

In describing the actual execution of the works the natural division of the working seasons will be followed. In the official reports made annually to Government the financial year has to be observed, and the progress reported annually is from 1st April to the 31st March following.

This does not agree at all, in the case of works such as those we are describing, with the actual working seasons. The season for work in the river bed of the Ganges or Jamna extends from the falling of the great floods at the end of the Rainy Season to the first rising of the river caused by snow melting in the Himalayas. This rising depends on the setting in of very hot weather and varies somewhat according to the season, but it is not safe to calculate on being able to work after the 15th of May. The floods due to rainfall in the hills do not come before July and the highest not unfrequently occur early in September.

From about the 15th September the river begins to fall rapidly. By about the end of the first week in October some work in the river bed can generally be begun. The working season is thus about 7 months in length, but a deduction for clearing sites from mud, silt &c. before work can be begun, and for dismantling at the end, reduces it for the purposes of actual progress to about six months. The works are sometimes liable to interruption by winter floods. One of these occurred in February 1875, the river rising suddenly as much as three feet; and a similar flood came down in February 1877.

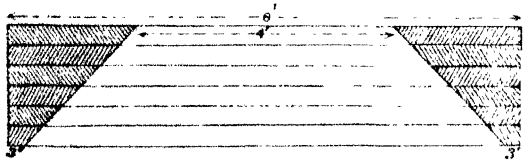
The first beginning of the Weir works was made in March 1873. In order to ascertain precisely what difficulties would be met with in keeping down the water and putting in the concrete and flooring of the Weir at the desired level, the Government ordered that a small section, 43 feet in length measured along the crest line, should be constructed as an experiment. Accordingly the wells and blocks were sunk and the concrete foundation of the floor put in. The experience so gained was a valuable

guide, in estimating the amount of pumping power required to ensure the certain execution of the work and in other respects. In sinking these blocks Fouracres' Excavator was used.*

This did not give good results here. Mr. Fouracres attributed the failure to the closeness of the Ganges sand as compared with that of the Sone where the machine was successful. This machine was used a little in the early part of the next season, but was subsequently thrown aside altogether and Bull's Dredger adopted.

Another point brought out by this experiment was the nicety required in piling the intervals between the blocks. The white sand of the Ganges is practically liquid when wet and nothing but *accurately* fitted sheeting will keep it out.

Shortly after this work was taken up a trial well was sunk near the site of the Weir Sluices to ascertain at what depth the clay bed which was believed to underlie the white sand would be reached. The well was an 8-foot circular one. The kerb made of fig (*gular*) or other common wood and of the cross sections shown in the sketch. A hoop of $\frac{1}{2}$-inch wrought-iron 6 inch deep was placed so as to form a cutting edge and the whole was secured by straps of wrought-iron on the outside. Steining rods were carried up through the kerb and the brickwork. This form of kerb was finally adopted for all the wells, but those which did not go to the clay were made rather less deep in section and were not shod with iron. In sinking this well the advantages of the cutting edge and bevelled form of section were clearly shown. The calculated displacement of the well and the cubic content of sand thrown out, which was carefully measured, were almost exactly equal.



In April the general lining out of the Weir works was done. The magistral line of the whole was of course the crest of the Weir. This was marked by pillars built on each bank at a considerable distance clear of the works on the prolongation of the line. That on the right bank is on the high ground. This line is at right angles to the general

* For a description of this machine, see No. 26 of the First Series of these Papers.

direction of the river from Rajghat to Narora. The other lines were marked in a similar manner. Ten feet bars made of well seasoned *sál* wood of T-shaped section laid on low trestles were used in measuring the lines,* three bars being used and care taken to keep them level. The water section was carefully measured trigonometrically. The same bars were used in laying out all the works.†

There was no possibility of beginning work on a large scale before the floods. No machinery was ready in the shops, and time did not admit of doing much. The site of the Left Wing however, being well removed from the action of the floods, offered an opportunity for beginning work on a small scale. It was most desirable to do this so as to have a nucleus for the large body of workmen which the next season's work would require, as well as to train the establishment. The news of work being set going would be sure to spread through the country and cause an influx of men in search of employment, and in fact had that effect.

In order to begin this work materials had to be conveyed from the Right bank. A floating bridge of country boats was therefore thrown across the river in the beginning of April. The superstructure was of *sál* beams 18 feet long and the intervals between the boats was 10 feet; the boats being 16 feet in beam. One boat was sunk owing to insufficient precautions to keep weight off the sides. The country boats on the Ganges and Jamna are very lightly made and in order to use them safely for bridging purposes it is necessary to distribute the weight carefully on the bottom only. This bridge was used by country carts laden with bricks &c. As all the weight is carried on one pair of wheels they cause more undulation than a four-wheeled cart of equal load and the effect of this on the boats has to be guarded against.

This bridge was maintained till 31st May and a large quantity of material was passed over it.

Work on the Left Wing wall was begun on 15th May. The wells are 12 feet in diameter. Twelve kerbs were laid and built on before the floods, and a commencement of sinking was made which continued through the floods.

Two 6-foot mortar pans purchased in Calcutta were set up close by, and

* The length of bar was taken from a comparison of 2 or 3 levelling staves.

† Captain Western made the Weir when measured by a steel tape 3 feet under the 3800. In 3800 feet there were 380 repetitions of the 10-foot bar and if the 10-foot bar were 0·095 of an inch under the standard of the steel tape it would account for this difference. As neither are authoritatively determined some difference was to be expected.

worked by a 8 horse-power portable engine. The tool used for sinking was Bull's dredger.*

At the same time surveys of the river from Rajghat to Narora were made and a system of works for training the river truly on the Weir was projected and the execution of it was begun in May.

The diagram section given on *Plate* V. shows that the site for the Weir sluices was at this time occupied in great part by the cold weather stream of the river.

The general programme of operations was to build first the Weir Sluices. It is obvious that this was the easiest way to get the weir completed across. During the progress of work on the Weir Sluices the Weir Proper was to be advanced as much as possible from both banks, care being taken to leave sufficient waterway for floods. When the sluices were ready the cold weather stream would be passed through them, and the Weir Proper completed across the bed of the river during a single cold season.

The first thing to be done then was to reclaim the site for the Weir Sluices, and in order to assist in this two floating tree spurs were designed to be thrown out obliquely to the stream above the site. The first of these was near Narora village and 3000 feet up-stream of the Weir crest Line, the next 1700 feet lower down.

These spurs were laid down before the floods in the hope that they would, by acting on the early freshes, give the river a new set eastward. They were maintained with considerable difficulty, partly owing to the nature of the bottom which allowed the anchors to drag.†

Another important preliminary work was the tramway to connect the Canal works with the Oudh and Rohilkand Company's line at Rajghat. Two proposals had been made with regard to this. One was to make it entirely on the metre-gauge, receiving and stacking all material on a stacking field at Rajghat. The other to bring the broad-gauge (4′ 8″½) down to Narora and there to form a depôt of materials, retaining the metre-gauge for the works. Both of these were abandoned in favour of a uniform gauge for the whole of the Canal lines.

The line when projected for the metre gauge had been laid out passing through the Workshops and the centre of the Station of Narora. The gradients and curves on this alignment were unsuitable for the broader

* Described in No. 8, Second Series, of these Papers.

† As is generally known to those who have worked in India, the anchors are large rough frames filled with heavy material. The spur is formed by small trees thickly tied on a hawser.

gauge and the line was inconvenient in other respects. It was therefore abandoned and that shown on *Plate* XI. finally adopted, the descent into the khadir being $\frac{1}{125}$ on a curve of 1500 feet radius. The construction of the line was begun in June and carried on during the Rains, a time of year very suitable for consolidating the kankar laid under the corrugated iron sleepers.

During and immediately after the Rains the lime kilns, six in number, on the Narora side (*Plate* XI.) were built and the lime-kankar stacking field, tramways, and sites for mortar-mills laid out. The mortar mills expected from England had not yet come. A small building was run up to serve as a testing room for limes and mortars, and it was established as a rule that all the mortar used should be constantly tested by taking samples from that made for actual use.

Season of 1873-74.—On the subsidence of the floods it was found that the tree spurs had been only partially successful in diverting the river off the site of the Weir Sluices.

In his anxiety to make them effective the Engineer in charge had prolonged them somewhat more than was quite judicious and they had burst in consequence. A succession of small spurs placed in echelon below them was resorted to and these by their gradual action had the desired effect, but it was not until the 13th January 1874 that the site for the Weir Sluices could be enclosed by an earthen *band*. Even then the water stood from 6 to 8 feet deep over a great portion of the site, and this had to be filled up with sand before work could be begun. The right abutment only was situated on original dry land and this was excavated and wells begun on the 10th December.

The Ganges was low in January 1874, but in February it rose, after the gauge had registered the assumed low water mark of R. L. 575·00 for two or three days only. In February and March it varied between 576·00 and 578·00 thus necessitating the laying of block and well kerbs from 2 to 3 feet above the level assumed in the designs, and adding to the sinking work.

By the middle of January the cold weather stream of the river had been pushed 500 feet from the right bank eastward and took up its position for the season with a tolerably uniform section. It was then possible to throw a bridge across. A pile-bridge of large scantling to carry the Oudh and Rohilkand Railway Company's locomotives had been included in the estimate for the works, but it was not thought worth while to go

to the expense of putting it up in this season. Instead of it a bridge of light piles was used, with the same superstructure which had served in the previous season for the floating bridge, and on this a metre-gauge tramway was laid which was carried as far as the Left Wing. A train of 40 wagons was run on it by hand-shunting.

Season 1873-74.

These wagons had been made for another purpose lower down the Canal and carried each 440 bricks or 33 cubic feet of material.* The bridge was opened about the 13th February and maintained until the 29th May. Large quantities of bricks, lime-kankar, red sand and fuel were carried over it for the commencement of work on the Weir Proper. Each wagon was loaded and pushed by four men and the train marshalled and managed by a conductor. These small wagons were not found so convenient for hand-shunting as a light class of 4 feet 8½ inch gauge wagons used at Okhla. The width between the buffers was not enough to admit two men safely and they were liable to cause serious accidents to the men.

As soon as sufficient material had been carried across a beginning was made on the Weir Proper. It was decided to build and sink the foundations for 800 feet in length measuring westward from the Left Wing. In fact, a length of 926 feet was done (including the 40 feet done in 1872-73) and the blocks and wells were fully sunk by the beginning of July. There were 81 square blocks and 104 circular wells in this work, besides other blocks in the partition lines.

During the season the well sinking of the Left Wing was pushed on, all the wells, 27 in number, were built and by the end of the Rains of 1874 were sunk to clay. It was impossible to force them into the clay without means of loading, which were not then available. Pumping was not resorted to during this season except to a small extent. Some was done in order to get in the foundation wells of the down-stream return wall of the Left Wing and, at the end of the season, to complete the sinking of a few wells in the Weir Proper on the left bank.

The chief work of this season was the foundations of the Weir Sluices. As fast as the site was reclaimed sand from the excavation of the Canal Head and Lock sites was tipped in by means of small metre-gauge tram-

* 355,000 cubic feet of material were carried over the bridge besides a large number of kerbs and other things. Its cost including waste of material was Rs. 3940.

ways, and as soon as the sand rose above water kerbs were laid and built upon. The non-arrival of mortar mills from England caused some delay but others were got in Calcutta and elsewhere by degrees. One six-foot, one eight-foot, and two seven foot pans were set up on the right bank to supply the Weir Sluices; also a mill of rather nondescript pattern sent from Roorkee. Two six-foot pans were fixed at the Left Wing to supply the works there.

Season 1873-74.

The total number of blocks in the Weir Sluices is 232 and of wells 86, all of the latter having to go into the clay stratum. During the season 217 blocks and all the wells were laid and sunk, wholly or in part. It had been hoped that the sinking work of the sluices would be completed during the season. The work however was greatly impeded by rises of the river in February and March. It also suffered from delays in getting kerbs and other essentials, owing to the Workshops not being yet organised and fitted completely.

Work was finally stopped on the 2nd June by a sudden heavy rise in the river. Previously to this the first 8 of the deep wells in the Weir Proper adjoining the Sluices had been sunk, to form a protection to the twelve-foot wells of the Left Abutment from a possible lateral scour during the floods, and the whole site of the Weir Sluices had been enclosed by a defensive work of block kankar.

This was run out on the up-stream side parallel to the face of the work at a distance of about 60 feet from the front line of blocks. It was carried as far as opposite the seventh well in the Weir Proper and then down-stream, passing over this well, until clear of the curtain line of eight-foot wells. A return parallel to the up-stream face enclosed the work on the down-stream side. The top of this embankment was placed at R. L. 591 the foundation level being about 575. The top was about 5 feet wide at first and the slopes ½. To guard against the scour in floods the N.-E. angle was thickened inside and it stood well through the floods though soundings of 40 feet were frequently taken close to it. The work required 620,000 cubic feet of block kankar, out of which 275,000 cubic feet were subsequently recovered and used elsewhere.

The remainder must not however been considered *lost* as it forms a valuable defence to the finished work against scour, especially that part spoken of as the N.-E. angle, and will check the scouring action of water running to the Weir Sluices when open. The whole

of this material was brought in from the depôts near Aligarh by the Oudh and Rohilkhand Railway Company's trains direct to the work.

Season 1873-74.

The tools used for sinking the wells and blocks were principally Bull's dredgers, as mentioned already. An improved sort of native jham obtained from Messrs. Marillier and Edwards of Calcutta was also used with very good results. Some of the petty contractors had very expert divers, and when these were at hand the progress made with this tool was better than with the dredger. Wells have been sunk with it upwards of 7 feet in one day. Two sets of regular dress divers were also employed and were of great service in bringing up large pieces of kankar and sandstone, which were met with in some of the wells. No old trees or sunken boats, such as sometimes have given so much trouble in well sinking, have been met with at Narora.

Canal Head.—In order to provide means of keeping the workmen together during the floods of 1874, as well as to steal a season, if possible, for the progress of the Canal Head the site for this work was excavated and kerbs laid and built on before the rising of the floods. The wells were raised by temporary brickwork above the flood level and sinking was begun when work was stopped elsewhere, and was continued until the re-opening of the other works.

The progress of the works has now been traced to the end of the first working season, that of 1873-74. We will now glance at some necessary auxiliary work done at the same time. The tramway was completed into the khadir by Christmas 1873. A small canal Railway station and telegraph office was established close to the Weir Sluices, and a station master appointed to work the khadir tramways under the canal officers. During the working season and the floods of 1874 the sidings to the kankar stacking ground and Canal Head were also laid down. Also a line to lead to the up-stream side of the Weir Sluices and one to the site of the Lock.

In the month of December 1873 the formation of the canal banks within the Station (or Cantonment) was put in hands, and completed by grassing the slopes in time to prevent this being cut away by the rains. The whole consist of pure red sand and had to be covered with a thick coating of vegetable soil and grass brought from the khadir below. The completion of this work afforded a level terrace road rather more than

half a mile in length overlooking the river, making a great improvement to the place, which however was at no time a very desirable place of residence. Several thousands of trees were planted in 1873 and 1874 and did well, especially the *shisham* and *sirris*.

A system of permanent triangles was established, and marked by brick pillars, for an annual survey of the river. Gauges at intervals of one mile were established and observed daily during floods. These extend from a point 6 miles above the Weir to Ramghat, 4 miles below it, and it is expected that the result of observations, when taken for several flood seasons after as well as before the construction and completion of the weir, will afford valuable data for calculating the effect of Weirs on a large scale in altering the regimen of a river.

During the rains of 1874 two out of the four nine-foot mortar pans were received from England and later the other two. The other mills were re-arranged during the slack season and fixed as described at page 26.

Some special bricks were adopted for the coming season. The first contract for a hundred lakhs of bricks was completed before the rains and a new one for the same quantity made in September. In 1873-74 voussoir headers and curved stretchers were used for the wells, the bricks being of the usual size, $9\frac{1}{4}$ inch long. A new brick the headers of which were $11\frac{1}{2}$ inches by 5 inches in mean width and the stretchers $10\frac{3}{4}$ long by 5 wide was adopted instead, the thickness being $2\frac{1}{2}$ inches only. These burn very well and make excellent work in wells of about 18-inch steining, the bond being very strong. A closer brick for plain work (as suggested by Garbett in his book on measuring) was also adopted. Its size is $9\frac{3}{4}$ by $6\frac{3}{8}$ by $2\frac{3}{4}$ and it has been found most useful in various ways.

The collection of Block and Lime Kankar went on regularly. Also that of the ashlar required, and its fitting up as described already. Several new houses were built in the latter part of the working season.

Season of 1874-75.—Before proceeding to describe the season's work some of the preparations made for it will be noticed.

Pumps.—Four 6-inch Gwynne pumps had been supplied from England. These were obviously not enough to ensure success in so large a work as the Weir Sluices (having an area about 450 feet by 150), besides which some power was required for the Weir Proper. Two 12-inch Gwynne pumps with a 12 horse-power portable engine for each were purchased

from the Oudh and Rohilkhand Railway Company, which was the only available source. The pumps were new and magnificent machines, but the engines had done a good deal of work. Two Woodford pumps were also purchased in Calcutta. A very convenient timber frame was made in the Narora workshops for each pump. It had screws for traversing it in two directions and an arrangement for raising and lowering the pump easily, when fixed over a well.

Portable engines suitable for the smaller pumps had been sent from England but one or two were added by local purchase. Three steam hoists were purchased. These were intended in the first instance for working sand-pumps, obtained from the Agra Canal stores, and two large-sized Bull's dredgers. They were used for working the large dredgers but the sand pumps were not used as it was found they could not compete (in the pure sand) with the ordinary hand-dredger.*

Later these hoists were used for other purposes. One, which had about 3 horse-power, worked a couple of concrete cylinders on the Weir Sluices and the other two were used for pile-driving. Two concrete-mixing cylinders, of the pattern known as Ridley's, were purchased. One of these was intended for handpower but it was found better to work it by steam. The other was of a larger size, and answered so well that one like it was made in the Workshops.

In order to save time and trouble in getting pumps fixed and to obviate the necessity of having to use the foundation wells for pumps, in some cases an inconvenient arrangement, two wrought-iron cylinders were prepared for the express purpose of receiving pumps. These cylinders are $3\frac{1}{2}$ feet in diameter and 12 feet long, or deep, made of $\frac{1}{4}$-inch iron plate. Round the inside of the bottom a piece of $2\frac{3}{4}$-inch angle iron was riveted. Above this was placed an india rubber packing on which fitted water-tight a wooden bottom to the tube. At the top were three large eyes to receive hoisting tackle.

The tube was pierced with three sluices, each 12 inches wide and 24 inches deep, opening downwards. The sill of the lowest sluice was placed so as to be, when the tube was in position, a little below the level to which it was required to lower the water. The top of each sluice was placed on a level with the sill of that above it.

* Sand pumps are very effective in sand mixed with stones, where the dredger is useless.

These tubes require only a few hours to sink them in sand, with a small Bull's dredger and a load of 6 or 7 tons. When sunk the bottom was put in by divers so that no water (bringing sand with it) can rise from the bottom. The top sluice is opened gradually down when the pump is started, and as the water falls the second and the third. If pumping was suspended the sluices were at once closed and, together with the bottom, prevented that blocking up by sand which so often causes delay in pumping.

Another provision for the coming season was a large quantity of sheet piling. The sheets were of *sâl* wood very carefully dressed and fitted. The guide piles and waling pieces were all of the same timber. Some very handy wrought-iron ringing engines were also made up in the Narora Workshops. They were on a timber framed platform with runners for 4 feet 8½-inch gauge, the upper part of angle-iron. The monkeys for these were cast in a small cupola set up in the Shops and weighed 4 cwt.

The programme for the season of 1874-75 had been as follows :—

1. Complete the Weir Sluices, so as to be able to pass the river through them after the rains of 1875.

2. Push on the Canal Head.

3. Build and sink the deep wells of the Weir Proper extending over 500 feet from the Weir Sluices, and also put in the concrete floor of the part near the Left Wing where the wells had been already sunk.

At the end of the floods of 1874 the state of affairs was as follows :—

In the Weir Sluices all the blocks and wells were in hand except 15 of the former. On an average each block had 8 feet more sinking to be done to it. There was also a good deal of sinking yet to be done on the wells.

In the Weir Proper 8 of the deep wells had been partly sunk, on the right bank, covering 70 feet from the Weir Sluices Eastwards; on the left bank the foundations for a length of 920 feet had been done, including the 40 feet done as an experiment in 1873.

In the Canal Head nearly all the 105 blocks were more or less advanced in sinking.

Floods of 1874.—The floods of 1874 had been rather heavy, the maximum gauge reading at Narora being R. L. 585·80, showing a rise of nearly eleven feet above Low Water. A measurement of the river

taken when the gauge read 585·20 gave as the result of calculation a discharge of 141,000 cubic feet per second. Probably this might be increased to 160,000 to represent the maximum discharge of the year.

The position of the deep stream after the subsidence of high floods at its crossing over the Weir Line, and the direction of the stream there, were of course elements of the greatest importance as affecting the season's work. Early in the flood season the conditions seemed likely to be tolerably favourable. The main stream of the river then passed about half a mile off the *village* of Narora and came down tolerably square on the weir line. Had this continued it would probably not have been very difficult to push the river further East after the floods and reclaim the site for the deep wells, in the same way as was done for the Weir Sluices in the previous season, and so to have carried out the original scheme of work. But towards the latter part of the floods the course of the main-stream underwent a serious change. The flood cut heavily into the khadir land at the point where Groin No. 3 is marked in *Plate* III., eating out a bay there. The rebound brought the stream heavily against the Narora side near the Inspection House, and a channel was formed which, after the subsidence of the floods, left the stream setting into the re-entering angle between the Canal Head and the Weir Sluices. This naturally caused it to rush out round the kankar protective works of the latter with great force, and kept up a heavy scour along them. The lead still showed 30 feet of water over the sites of a great part of the proposed wells. The same cause prevented the construction of the pile bridge in the early part of the season, and the tortuous course of the stream rendered a diversion tedious and uncertain. Under these circumstances the extension of the Weir Proper wells from the right bank had to be abandoned. The work ultimately substituted for this will be described later.

Working Season of 1874-75.—On the subsidence of the floods it was found that a heavy deposit of black slime had taken place in and over the blocks and wells of the Weir Sluices. This was due to percolation through the kankar embankment, though it was rather difficult to account for the very slimy nature of the deposit in a river the bed of which generally of pure white sand.

This deposit varied in different parts from 3 to 7 feet in depth and amounted to not less than 350,000 cubic feet on the work. The un-

finished wells and blocks were filled up with it and it was a matter of great difficulty to get them cleared.

Season 1874-75.

Early in November a 7-inch Gwynne and a Woodford pump were fixed in two of the curtain wells, No. 6 and No. 7 counting from the right bank.* By the first days of December the sinking of blocks and wells in the Weir Sluices was again in active progress. The closeness of the blocks to one another made it very troublesome to sink them, and had some of those in the second and third lines been omitted in the design, and compartments formed to be filled with concrete, a good deal of valuable time would have been saved. It is very probable that the whole of the blocks would then have been sunk in the first season, instead of not being complete till February 1875. The clearing and filling up with concrete of the narrow intervals was a very tedious task, and could not have been done in a solid manner had not the pumping power been very affective.

By the end of February, the sinking of the blocks having been completed and a number of the intervals closed, it was possible to make a beginning on the consolidation of concrete in some of the eight bays, or compartments, (each 42 feet by 111 feet) into which the foundation of the open parts of the floor is divided.

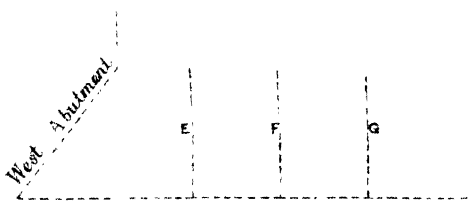
It had been found impossible to get the wells of the abutments and curtain line down to their proper depth in the clay without the means of weighting them, for which purpose nothing so effective as railway bars has yet been found. Large boxes filled with sand were used at Narora, piled to a considerable height one above another, and other expedients were tried without success. Early in 1875 a thousand tons of rails were purchased from the State Railway Department. Each well, it was found, required from 100 to 200 tons to get it down. These rails were delivered in March, and were brought into use as quickly as possible. It had become clear that the wells could not be finished in time to serve as part of the coffer dam for the concrete. Consequently a line of sheet piling was begun early in February, at a distance of 15 feet clear from the curtain wells, and thus two of the central bays were prepared for concreting by the 5th March. The work had been delayed nearly a fortnight in February by a rise of the river, very unusual at that season, of no less than 3 feet in one night.

* All the wells and blocks were numbered. The lines of blocks were distinguished by letters A to K, each block being marked with its number. The wells under each abutment and those in its line were similarly numbered: those in curtain line from West to East.

Season 1874-75.

The pumping arrangements were as follows:—One of the 12-inch Gwynne pumps was fixed in No. 18 well of the curtain line, facing the bay which was to be concreted first. This pump remained in the same place to the end of the working season. The other 12-inch pump was fixed in a wrought-iron cylinder sunk close to one of the curtain wells in the next bay to the East of the last named. These two pumps drained the two bays near them, which were excavated to receive concrete, and kept down the water in the alley formed between the line of curtain wells and the sheet piling.

The Woodford and the 7-inch Gwynne pumps fixed, as mentioned already, in the neighbourhood of the West Abutment were left in their places and kept down the water which drained into the Canal Head, as well as in the end bay between the abutment wells and line E.



A line of wooden caissons 16 feet long by 6 wide and 10 deep was sunk in a bent line parallel to the right or West abutment wells and at a safe distance from them. These were filled with concrete. When the concrete was fully set the ends and inner sides of the caissons, which had been specially fitted, were unkeyed and drawn up. The intervals between the ends were closed by piling and concreted and the mass of concrete thus formed acted as a temporary abutment. Parallel to the East abutment a line of sheet piling was used The concreting of the floor thus went on independently of the deep wells.

To keep down the water in front (or up-stream) of the work it was found necessary at this time to fix the spare 7-inch Gwynne pump on that side. It first stood in the centre block of the third line. Later it was moved to nearly the eastern end of the second line. This pump enabled us to concrete the intervals between the blocks very efficiently, and also kept the water in front of them from overflowing the floor. It would however have worked still better if on being moved it had been

placed in a wrought-iron tube just *outside* the work in front, instead of within it, and thus created an outward draught instead of an inward one. It was being moved at the end of the season when work was stopped and not until it was subsequently worked *outside* could the last of the intervals between blocks close by be closed up with concrete.

Season 1874-75.

When everything was ready the excavation of the bays was proceeded with, and the water having been reduced to the proper level six inches of dry brick ballast was laid down to receive the concrete at R. L. 567·0. Consolidation of concrete was begun on 5th March and continued uninterruptedly. The pumping was very satisfactory and every part of the floor was laid and consolidated in the dry.

The lime for concrete was all ground dry and stored in bags. Two concrete cylinders set up on the embankment enclosing the work, on the up-stream side, were used for mixing the lime with sand, equal parts by bulk of each being used. The supply of material was by a branch tramway carried over the Canal Head on a trestle bridge, and the cylinders were driven by a large steam-hoist and were fed from a platform laid level with the top of the hoppers.

The brick (broken to 1½-inch ring) having been soaked in tanks made up on the work was incorporated with the sand and lime mixture by hand, then carried straight to the work, laid and consolidated by ramming. An Assistant Engineer was specially employed to superintend this work. Very little water is required in mixing concrete which it is intended to ram. Common circular iron rammers were used, with a few square headed ones for use along the sides next blocks and sheeting. In a few days, under close supervision, the gangs got into a sort of drill and became very expert. The brickwork floor (12 inches thick) overlying the concrete was begun on the 12th March and extended as fast as the concrete was ready. It was laid in English bond.

The first stone of the ashlar floor was laid on the 3rd April. As it was of the greatest importance that the floor should be laid as rapidly as possible, special care was taken with the arrangements. The whole floor for the Weir Sluices had been fitted up on the ashlar ground by the 31st March. The blocks were each 5 feet long by 2½ feet wide and 12 inches thick weighing about 16¾ cwts. The ordinary Indian method of moving stone, by harnessing a large number of men (*bandhānis*) to each block,

was rejected as unsuitable where a large number of blocks had to be laid at one time. It would have required from 350 to 400 men to keep the masons supplied and led to a very inconvenient crowding on the work. Besides even when the stone is moved in this way gyns are required to enable the masons to set their stone properly. Instead of the *bandhánis* the supply of stones to the masons was effected by means of small trucks each carrying a single stone. A metre gauge traverse line was laid across the floor from each point in front of the work at which the ashlar was delivered by a gantry. At right angles to this traverse line a number of light moveable tramways were laid, each leading to one of the gyns at work. These light lines consisted of 12-lb. rail spiked to wooden planking. The small trucks were placed on small wrought-iron traversers which carried each block to the junction with the line leading to its proper place in the floor. From thence the truck was pushed along to the gyn for which the block on it was destined, while the traverser returned for another truck and load.

Season 1874-75.

The traverse line was on a slight incline and formed of 36-lb. rail, braced and tied with iron so as to be light and easy to shift. Weston's pulley blocks were used on the gyns. When the work was fairly under weigh there were 12 gyns in use, each laying about 12 blocks daily.

The delivery of the blocks on the floor level was done by the help of two gantries set up about 120 feet apart on the up-stream side. By means of these the blocks were lifted off the wagons, carried to a point over the ends of the traverse lines, and lowered 15 feet to the trucks below. The stone was moved by crabs resting on a wooden platform truck running on the gantries.

As the embankment in front of the work was too narrow to allow of points and crossings, large wrought-iron traversers were used to transfer the ashlar wagons from the main tramway to a siding under the gantries.

The work of laying ashlar was fully started by 12th April and continued without intermission, except on Sundays, until the 12th June. A requisition for the blocks required for the ensuing day was sent in every afternoon by the officer in charge, and the blocks were sorted out of the floor as it lay on the ashlar ground and loaded on wagons during the night. The sorting was done by means of "*bandhánis*" who carried the blocks to a crane by which they were loaded up in the wagons.

On the 13th June a rise of the Ganges breached the embankment en-

closing the Sluices, near its N.-E. corner, and filled the work. By this time the concrete work was complete up to the limits of the sheet piling and brickwork had been carried over nearly all the finished concrete.

Season 1874-75.

The greater part of the brickwork had in its turn been covered with ashlar.

The blocks forming the foundation of the superstructure had been filled with a hearting of two parts of sand to one of lime. They were left uncovered in order to allow the work to be inspected after the floods before building on them. This reduced the area available for laying ashlar on in the season of 1874-75.

Well-sinking in the abutments and curtain line was continued. At the approach of the floods the unfinished wells were raised by temporary brickwork to allow of sinking work being continued during the rains. This temporary work was laid in mud to save mortar and damage to the bricks,* but it was scarcely a wise economy for some of the work fell when the river rose on it, and some wells had to be supported by planks and bound round with rope to prevent accidents. Those wells the brickwork of which fell were of course lost for the time and no sinking could be done on them till after the floods. It should be noted that clay was met with under the Weir Sluices at a somewhat higher level than in the trial wells further East (the first trial well was near the East abutment) and it was decided in April 1875 to stop the wells when in clay at R. L. 545·0 instead of 543·0. Some of those in the West abutment got well in to clay at yet higher levels.

Before proceeding to describe the season's work on the Weir Proper that on the Canal Head must be briefly noticed. At the end of the floods of 1874 the work of block sinking had made considerable progress and it was then found necessary to stop it in order to force labour into the Weir Sluices. As sinking work was finished there the men were allowed to return to (the easier) work in the Canal Head so that before the end of May the blocks were all sunk and hearted with concrete. As the gangs employed in consolidating concrete in the Sluices ran out of work they were transferred to the Head. When the flood of 12th June came it found about one-third of the floor concrete laid; the first of the five

* Brickwork in mortar could not be taken down at Narora even after a few months without breaking the bricks.

bays into which the floor is divided having been finished, and the third partly so. Two of the other bays were cleared ready for concrete but the remaining one was obstructed by the trestle bridge leading to the Weir Sluices.

Season 1874-75.

It was very desirable to shift this bridge at a time when it was not wanted for use, in order both to improve the curves of the line and get the floor underneath finished. A clay bank was therefore thrown in to separate the Head from the Weir Sluices.

While this was being done a 12-inch pump was brought from the Sluices and put up over one of the blocks in the left Canal revetment. A 7-inch pump had already been working in the centre of the front line of curtain wells and these two together laid the work (area about 300 feet by 80 feet and head of water 18 feet) perfectly dry. Concreting was resumed on the 8th July and all completed, brickwork was laid over a great part of it and a small piece of the ashlar floor laid to receive the trestles, and thus obviate any necessity of breaking the bridge during the next season. This was done by 30th July and the pumps were then stopped.

River Wall.—The building and sinking of the wells for this work (47 in number) was pushed on during this season, and 41 of them were sunk and concreted before the floods. A bank of block kankar was built on the tops of the wells to protect the ground behind from erosion during the floods.

The foundation of the puddled clay bank faced with block kankar pitching which protects the river front in continuation of the River Wall and Lock Head was done at the end of this season. Orders to begin it were received in April, and it was carried on with some difficulty owing to the rising of the river in May. The clay had to be brought from Rajghat. It was carried to the work by means of a branch tramway laid on the tow-path.

Weir Proper.—The unfavourable turn taken by the main stream of the river towards the end of the floods of 1874 has already been described, and its effect in delaying the construction of the pile bridge, and in causing a change of the programme of operations on this part of the work, has been mentioned. The timbers available for the pile bridge, which was this year to carry heavy locomotives, were only 20 to 22 feet in length, consequently could not be used in more than about ten feet of

water. Whilst the river was falling no time was lost in endeavouring to divert the stream eastward. A series of tree spurs was thrown out in echelon above the work and these gradually took effect, causing silt to be deposited on the sites of some of the deep wells of the Weir. Pile-driving for the bridge was begun from the left bank on 16th January 1875. The depth of water had by this time been sufficiently reduced to allow of a spur of block kankar (an expensive material which we could not afford to use recklessly) being run out from the embankment round the Weir Sluices to protect the site of some of the wells. Under cover of this sand was thrown in and the kerbs for Nos. 409 to 414* wells of the Weir were laid on 12th February.

Season 1874-75.

The bridge was nearly completed on 18th February when it was delayed several days by a flood. A good deal of the pile-driving for the bridge in this season was done by crab-engines, a steam engine not being available until the work was about half done. The cost of driving each pile by steam was Rs. 3-12 against Rs. 5-3 by hand. The pile-engine and steam-hoist which worked it were both put on a large country boat, but as this was found hardly "stiff" enough it was decided to use two boats lashed together next season.

The pile-engines were found scarcely high enough to set the pile easily, so a thirty-foot engine was ordered for the next season and the work was then done very quickly.

The bridge was ready for traffic on 9th March and kerbs, bricks &c. for the new work on the left bank began to pass over.

The work taken up on the left bank in this season consisted in extending the weir foundations 500 feet more westward in continuation of the 900 feet done in the previous season. This was in substitution for the loss of length on the other bank.

More work could have been done but it was not advisable to encroach too much on the waterway left available for the flood stream. By the 31st March 9 more of the deep wells (on the right bank) were begun making, with the 8 of the previous season, 23 in all from the right bank out of the total number of 56 which had to be sunk to the clay bed. These 23 wells cover a length of 227 feet. The protective works

* The wells 422 in number are numbered from East to West.

covered nearly 200 feet more, taking both sides together, and consequently there were about 2000 feet of waterway $\{3800 - (1400 + 220 + 180)\}$ left clear for floods.

Season 1874-75.

In addition to sinking new wells the work of clearing out sand, concreting the floor and laying brickwork and ashlar in the work of 1873-75 was to be pushed on.

The whole of the blocks and wells in the new work were finished by the 17th May. Meanwhile concreting was begun from the trial block of 1873. A good deal of the concrete put in there was found to be bad. This was partly owing to the lime (supplied by petty contractors before our own lime burning arrangements were complete) not being good, and partly to the want of a perfect command of the water when it was being laid. All the defective work was taken up and made good, and work was carried on up to the 30th June. By that time nine compartments, or bays, of the floor, covering 448 running feet of Weir, had been concreted and brickwork laid over 200 running feet. The ashlar for 700 feet run was sent over, but only 112 feet run were laid.

During this season only three pumps were available for use on this side of the river. At first two 7-inch Gwynne's and one Woodford's pumps were used. Latterly one of the former was replaced by another Woodford, as it got so worn that it did not give full duty. During the floods the Gwynne pumps were lined with steel in the Narora Shops, which prevented their wearing and greatly improved their out-throw in the next season.

The difficulty of keeping the work dry in this season was increased by the backwardness of the deep piling between the eight-foot wells. This was partly due to a want of steam piling engines and partly to the difficulty of getting piles 20 feet long set between wells which had been corbelled to a square top. This difficulty was obviated for the future by corbelling* the wells sunk in 1875 to the outer side only, which is in fact all that is required to form the floor upon.

At the best piling between brick wells is an imperfect job, except for very shallow wells. It scarcely ever happens that two adjoining wells are both perfectly vertical, so that a perfect joint is very seldom possible.

* All round wells which had to carry any superstructure were corbelled to a square before sinking the last length. This saved much expense and was not found to cause any difficulty in sinking

Absolute dryness during consolidation of concrete was insisted on. In consequence of this, and the deficient pumping power, the progress fell somewhat below what was desired but not so much as to affect the final result.

Season 1874-75.

The pumps were placed on certain of the eight-foot wells which had been prepared for the purpose. When building them two circular holes, 12 inches in diameter and at different levels, were built on the inner side. These were filled up with brickwork in mud and plastered on the outside.

After the sinking of these wells was complete they were, instead of being filled, only concreted up to such a level as would admit of the pump standing below the lower hole. When required for use the holes were broken out from inside. The upper hole was used in reducing the water and clearing out the sand from the bays and the lower was placed so as to allow of the water being kept down *below* the lowest level at which concrete was to be laid.

A layer of 6 inches of broken brick laid dry was used below the concrete, to form a bed for it and prevent sand from working up into it during consolidation.

Work was continued on the left bank until 30th June when the back-water from the river rose so high as to block the outfall for the drainage.

On the right bank six of the 23 deep wells were finished and, a talus having been laid behind (down-stream of) them, the floods were allowed to pass over them all. It was an oversight not to have filled the unfinished wells with *clean* sand. During the floods they got filled up with slimy mud which it cost a great deal of time and trouble to remove before sinking could be resumed in the next season.

To protect the end of this line of deep wells, a block kankar spur 200 feet long was placed at right angles to the weir line, covering the last well. As this spur would be exposed to the full force of the deep stream in floods it was sure to require additional material. To supply this a boat bridge was laid connecting its lower end with the tramway below the Weir Sluices. The flood-action on this spur was very violent in the earlier part of the floods, before the recent additions to the river works had had time to take effect.

The west end of the Weir work on the left bank was also protected before these floods. In the previous season it had not been necessary,

but as it was intended that the river works should now throw the force of the flood stream against the left bank a strong embankment faced with large kankar was thrown up. This was further protected by a spur 60 feet long carried up-stream, to keep the spill water running back to the channel from cutting the embankment. A large reserve of block kankar was stacked near in case the work should be seriously attacked by the flood. A similar spur was thrown out on the down-stream side.

With the end of this season the work had reached a critical stage. The foundations for the weir had been sunk over a length of 1400 feet from the left and 200 feet from the right bank. The necessary protective works at the two ends covered a length of 200 feet, making a total of 1800 feet out of the 3800 feet between the abutments of the Weir Proper, and leaving a waterway of 2000 feet available for floods. The floods of 1874 occupied a waterway of 1700 feet in width. It was clear therefore that until the *whole line of wells* could be completed, from bank to bank, in one season it would not be safe to do much more in the way of extending the foundations of the Weir. The most that could have been ventured upon would have been to sink the remaining 33 deep wells, which would cover just 300 feet and reduce the clear waterway to 1700 feet. To do more would have exposed one or both of the ends of the unfinished line to a violent attack from the succeeding floods, and might have led to some of the wells being upset. It would also have forced the flood to scour out a deep channel for itself and thus have delayed the progress of the work in the following season, just as it was delayed in that of 1874-75.

The Ganges training works, which had been going on regularly since 1873, were now approaching completion. It was expected that after the floods of 1875, the stream would be forced to flow nearly square across the weir line, and would at the same time be pushed away from the right bank, where it had given so much trouble in the earlier part of the two former seasons. If so the early construction of the bridge would be possible, but no dependence was placed on this and a supply of material more than sufficient for the eight-foot wells had been already stored on the left bank before the bridge of 1874-75 was broken up.

Under these circumstances a project for closing the river by the line of curtain wells, and turning the cold weather supply through the sluices

was submitted to the Government N. W. Provinces in August 1875. The programme for the season of 1875-76 was as follows:—

Project for closing the river.—As soon as the water fell low enough, the building and sinking of foundations was to be resumed on the left bank, using the materials already stored there.

As the water fell in September spurs were to be put in on the right bank to deflect the stream off the sites of the deep wells. It was reckoned that this could be accomplished and the sites prepared by the middle of December. By the middle of February all the eight-foot wells up to No. 300 would be sunk, making 1300 feet run of new work on the left bank, while on the right bank the wells from No. 366 to No. 400 would be in a forward state. A gap of 66 wells or just 600 feet would be left for the river. Three months would then be left in which to close the river, diverting the water through the sluices, build and sink the remaining 66 wells, and prepare everything for the floods.

It was calculated that the sluices could be got ready to be opened for the river to pass through them by 15th February. A scheme for closing the river was at the same time sketched out.

Floods of 1875.—The rains began on the 24th July. Early in August the course of the river began to change and by the middle of August the improvement in the course of the flood stream was very marked, the deep stream working over to the Eastward and impinging on the left bank above the Weir. A gang of men was kept at work loosening the bank with crow-bars, and the soil was rapidly carried away by the floods. By the end of September the river had encroached 1000 feet opposite the Inspection House, and the erosion extended down towards the Weir, getting rid of a large patch of land which obstructed the approach to the Weir.

Season of 1875 76.—At the end of the floods the main stream, which early in August had flowed in a deep and rather winding bed passing close to the kankar spur on the right bank near the Weir Sluices, had moved 1400 feet to the Eastward and was flowing nearly square across the weir line in a broad and shallow bed. The state of the river was most favourable for a closure. The main stream was exactly in the position most convenient for the operation and the cross section all that could be desired. There were no deep holes, and it was possible to begin the pile bridge very early in the season. The old bed left on the right bank

was now very narrow and nowhere more than 18 feet deep. Moreover the velocity in it was very small, not more than that half a foot per second, so that there was no difficulty in closing it by a *band* and preparing the sites of the deep wells. East of this old channel was a shoal of some extent left dry, just at the site of No. 366 well, the easternmost of the deep ones. Eastwards of that the water was shallow for a length of 600 feet, so that there was no difficulty in carrying an embankment for the tramway from the right bank up to the edge of the main stream.

Season 1875-76.

By the 3rd November the channel on the right had been closed by an embankment and the kerbs for 600 feet run of new wells laid out.

Under these favourable circumstances the Chief Engineer approved of the programme sketched out in August being adopted and orders to go on with it were received on 7th November. As these orders had been expected and everything short of actually beginning to build had been got ready, work was commenced at once.

The season's work will be described in the same order as before.

No new machines or appliances were made or purchased except the following:

One additional tank engine for the canal tramways purchased from the Oudh and Rohilkhand Railway Company. Fortunately they had one to spare of the same pattern as the two previously bought.

Two additional Gwynne pumps. A 10-inch pump was obtained in Calcutta which proved a valuable addition to the pumping power for the Weir Proper, throwing 1500 gallons per minute against 650 only which the 7-inch pumps throw.

A trestle bridge to carry the tramway over the Weir Sluices when the river was to be closed, was ordered in July and made up in the Narora Workshops. It was to stand on the ashlar floor and was 480 feet long in bays of 14 feet span. An additional hundred feet length of pile bridge was also prepared for the Weir.

Weir Sluices.—It was essential to the success of the season's work that the Sluices should be ready to pass the supply of the river when the opening left for it in the line of Weir wells had to be closed. To allow a margin for safety, this date was fixed at 15th February, although it was not absolutely necessary to begin the closure quite so soon. Every effort was therefore made to get the work completed by 15th Feb-

ruary. The sinking of wells in the Weir Sluices had been cont during the floods. Actual work was opened fc

Season 1875-76. season in the Canal Head, the floor of which is 3 feet higher than that of the sluices. Pumping was begun there on 5th November (the pumps used in July being still in position after repairs). On the 9th the work was dry and brickwork was resumed on the floor. Ashlar work on the floor was resumed on 12th November and went on continuously to completion.

The superstructure was begun in this season. It was desirable to get it above H. W. M. of floods so that it might be continued during the rains. The work went on more or less rapidly according to the demand for labour on the works which were of more immediate importance.

River Wall.—Work was carried on here in a similar way. By the 1st April it had reached R. L. 582 and so was available to employ some of the bricklayers, during the floods of 1876.

On the Left W. ing wall nothing was done in this season. The rails released from the Weir Sluices in March were taken over to load the wells.

The arrangements for pumping in the Weir Sluices were as follows:

One 12-inch Gwynne pump was placed in a wrought-iron cylinder outside the work behind the west abutment and close to No. 16 well in it. The other 12-inch pump was in a wrought-iron cylinder close to No. 13 well on the East abutment, outside the work, and a 7-inch pump was placed in one of the front line of blocks on the up-stream side of the work. In order to lower the water enough to allow these pumps to be fixed properly, a 7-inch Gwynne pump was worked in No. 26 eight-foot curtain well from the 16th November. The permanent of pumps was thus got so as not to require alteration afterwards. Each pump was surrounded on the outside by sheet piling connected with the permanent work.

On the 22nd November, when the works were inspected by Sir Andrew Clarke, Public Works Member of Council, the floor was nearly dry. Concreting and brickwork were resumed in the Weir Sluices on 13th December. By this time the embankment between the Canal Head and the Sluices had been removed and the pumps in the Canal Head were no longer required. Ashlar work was immediately resumed and the whole went on without interruption to 1st March. By that time the well

ing had been finished the floor joined over the lines of wells, the abutment walls and piers had been raised six feet above the floor (to R. L. 578) and the work was ready to allow of the river being turned through it. Afterwards the superstructure was raised high enough to prevent its being submerged by the floods.

Season 1875-76.

Weir Proper.—When, on the 6th November, the Chief Engineer's orders to close the river were received brickwork was at once begun upon kerbs, which had already been laid in position on the left bank of the river. A day or two later work was begun upon the new deep wells on the right bank. By the 14th 63 new wells were in progress and the sites for 49 more were ready for the kerbs.

The additional 100 feet of pile bridge which had been got ready for this season gave the bridge a clear waterway of 600 feet. The construction of the bridge was begun, from the left bank, on 3rd November. This season the pile-driving was done entirely by steam. The thirty-foot pile engine, fitted on a raft formed of two country boats lashed together and decked with railway bars, worked very well and had ample "stiffness" for placing the heavy piles. The bridge was ready on the 4th January. It had a navigation opening of 30 feet spanned by iron girders framed and braced together and a footway 4 feet wide. To pass boats the iron girders were raised and removed by bringing a boat under them.*

At each end of the pile bridge an abutment of block-kankar was formed, to prevent any erosion of the banks by a flood, or during the operation of closing. A wing of block-kankar was put down-stream of each abutment, that on the right bank being prolonged to No. 3 trial well. As the bridge was formed block-kankar was put in; first round those piles where scour was going on, and then gradually extended till a level floor at R. L. 570 was formed under the entire bridge.

On the left bank, two 7-inch Gwynne pumps were in position and working by 5th December, to allow of the sand being cleared away and the bays made ready to receive concrete. Later two other pumps (a 10-inch and a 7-inch) were fixed and the work of concreting, brickwork and ashlar went on steadily. On the completion of the pile bridge, the steam pile engine was sent to the curtain line of wells on the left bank, and another was got to work on the curtain line of the Weir Sluices. After finishing in the Weir Sluices, the latter worked along the Weir from the right bank.

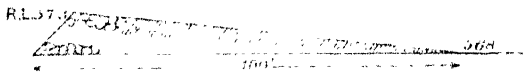
Season 1875-76.

It was a great advantage to the work on the Weir Proper that the deep piling was, this year, well in advance of the concreting work. The acquisition of a 10-inch pump and the great improvement in the old pumps from the steel lining also helped to make the work on the Weir Proper easier than in the last season.

The writer left the works in December 1875 and resigned his charge to Captain J. H. Western, R.E.

The trestle bridge for the Weir Sluices was put up in February; the rail level on it being at R. L. 582.

By the beginning of March all the twenty-foot wells of the Weir were finished and all the deep wells were in progress; and a dozen of the latter were complete. The pile-bridge stood between wells No. 278 and 234. Preparation for the diversion of the river to the Weir Sluices was begun in the middle of February by filling up the hollows in the river bed with block-kankar, and this forming a continuous bar between the abutments of the pile bridge. The section of the bar is shown in the sketch.



The crest of this was one foot above the level of the Weir Sluices floor and the bar formed a platform on which to raise the dam required to close the river and make the actual diversion. A diversion channel 250 feet wide was excavated down to the water level, leading to the Weir Sluices from the main stream above the pile bridge, and three cuts 70 feet wide were made through the spoil banks below the sluices.

On the 2nd March the raising of the loose stone dam was begun. The material was brought in by train loads from the depôts near Aligarh by the Railway Company, and thrown into the river from the bridge. At the same time the embankment round the Sluices was cut. By the 5th the dam was raised to R. L. 580 and the diversion was complete. The success of the arrangements was rendered more easy than it might have been by the small volume of water then in the river.

As soon as the kankar *band* was finished a facing of loose burnt ballast thrown in on its up-stream side over which were placed screens of

grass and matting. Clay was then thrown in and when percolation had thus been stopped a sand *bund* was formed and the sites of the remaining 63 wells thus laid dry. This was done by the 11th March and kerbs were at once laid and built upon. 49 out of the 63 wells were fully sunk within a month of laying their kerbs and the others soon after.

Season 1875-76.

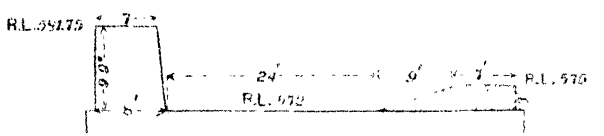
Work on the Weir was closed on May 15th. All the closure wells except one (which had to go about 18 inches more) had been sunk and all the deep wells except five. These last (Nos. 394 to 398) had got upon the remains of the protective works of 1875 and had to be filled up with sand and left to be completed next season.

At this time the concrete work in the floor had been finished over a total length of 1600 feet.

The front line of blocks was sunk for 440 feet from the right and continued 500 from the left. This brought the end of the line on the left bank just half way across the Weir.

At each end wells were substituted for the last three blocks, and they were sunk 10 feet deeper than the blocks to provide against scour during the floods of 1876.

In February 1876 a modification of the Weir section was ordered. It originally had been thus—



It was now decided to abandon the cistern and make the floor flush at R. L. 572 by omitting the shaded part. The original section had been completed for a length of about 200 feet on the left bank in 1874-75, the Weir wall being built also up to the level of R. L. 575.

The idea of the original section was to protect the floor from the action of the falling water by the three-foot cushion of water which would be formed over it, but it was obvious that the three-foot wall over the curtain wells would increase the action on the talus. Finally it was decided that the talus wanted protection more than the floor, and hence the cistern

At the time that this change was decided on orders were given to keep the Weir work down to R. L. 572, *i.e.*, not to build the three-foot of Weir wall as before arranged to do, and to cut off the curtain wells at 572 instead of leaving them at 575. The immediate effect of this was unfortunate. The floor of the Weir Sluices is also at R. L. 572. Consequently there was no draw towards the Sluices, such as would have been caused by the 3 feet difference of level, and after the floods there was no stream at all through them; when they ought to have been carrying the whole of the cold weather supply. Instead of that it passed over the Weir. The Weir Sluices were in fact useless during the working season of 1876-77 and a tedious and expensive diversion of the river, occupying 26 days, was rendered necessary to move the stream from one part of the Weir to another.

The talus of the Weir Proper was laid this season to a width of 60 feet only. Its average depth was $3\frac{1}{2}$ feet. A temporary apron was laid on the up-stream side of the twenty-foot wells to protect them against any scour on the up-stream side. It was 25 feet wide and $2\frac{1}{2}$ deep. The sand had therefore to be cleared out down to R. L. 569·5. Three steam pumps were at work for three weeks to effect this.

The rains of 1876 did not begin at Narora until 12th July, but the river rose in June to about the average height due to the melting of the snows.

The main stream of the river continued where it had been before the closure, namely on the left bank. Previous to the floods the cuts shown in the diagram in *Plate* XV. had been made, to conduct the water to the left part of the Weir. The set of the river greatly assisted the action of these cuts. Men were employed to loosen their banks, and by the end of the floods the ground on either side of the Weir was washed away over a length of 1600 feet, measured along the Weir.

In October the main stream of the river flowed over the finished part of the Weir, passing about 300 feet from the Left Wing. The width of the stream was 400 feet. The rest of the Weir and the floor of the Weir Sluices were covered by a sand bank which rose in some places to R. L. 584, or 12 feet deep on the work. With this mass of sand in the way and no advantage in the levels of the floor to help the diversion, it was considered hopeless to divert the stream to the Weir Sluices. The plan of operations for the season therefore was to leave the river untouched

while a part of the Weir (chains 20 to 26) 600 feet in extent was completed and the Weir Wall built up to R. L. 576. Then to divert the stream Westward over this portion and then raise the wall where the stream had previously been flowing.

Season, 1876-77.

The work to be done on the Weir was to complete the front line of blocks (over a distance of 1500 feet) with their cross blocks and to finish the whole floor. There was a length of about 2200 feet remaining to be concreted, about 2800 to receive brickwork and ashlar floor. Also to build the Weir wall 4 feet high, or up to R. L. 576; to add to the talus and form the apron. The programme seemed easy and had the Weir Sluices been working would probably have proved so, in spite of the heavy rain and most unusual floods which characterized the season.

The Left Wing wall wells were finished during the rains of 1876. In October the superstructure was begun and it was built up to full height, except the coping, by the early part of January 1877.

The River Wall was brought up to coping level during the rains.

The Canal Head was brought up to roadway level by July. During the season of 1876-77 the parapet and Cast-Iron grooves were added.

Weir Sluices.—Work on the superstructure was suspended in April 1876, in consequence of some modification to the original design. It was not resumed until December 1876 and the lower story was completed in March 1877. The upper story and terminal towers were approaching completion when the writer visited the works in July 1877.

Lock.—Orders to begin the Lock were received at the end of November 1876. The foundation blocks were built and sunk during the earlier part of the season of 1876-77, and by July the superstructure was finished except coping.

Weir Proper.—The commencement of block sinking was somewhat delayed by the mass of sand which had to be excavated, and by the block-kankar temporary apron which had to be removed before kerbs could be laid. Block building was begun on 18th November. On the 16th January the concreting work on the floor was resumed. By the end of February all the blocks required to complete the Weir had been sunk and hearted with concrete and the whole of the floor concrete put in. There only remained to put the brickwork and ashlar on part of the work and to

build the Weir wall. It was decided to make the wall in this season 4 feet 9 inches high at the Left Wing and 4 feet only on the right reducing the height gradually from left to right. This was done to bring the stream in the floods back to the Weir Sluices.

Season 1876-77.

On the completion of chains 19 to 27 of the Weir (measuring from the right) a trestle bridge 400 feet long was put up and the diversion of the river over this finished part of the work begun. It took 26 days to effect this diversion, from 19th February to 6th March. A bridge-of-boats was laid across the stream on the up-stream side of the Weir. The kankar was carried from the bridge and laid by hand on the ashlar floor. It thus took a good deal longer to place the kankar than in 1876 when it had only to be dropped overboard from wagons standing on the pile bridge. Moreover there was (owing to the extraordinary rains) more than four times as much water in the river this year than at the same time last season, and in addition the stream had to be forced over a bed the bottom of which (at the Weir wall) was 4 feet higher than the one it was to leave.

Just after the diversion was begun, one of the floods which were frequent in this season came down, stopped the work, and damaged some of the *bands* formed to protect those parts of the Weir where work was still in progress. Previously to this, on 8th February, a 12 horse-power engine was washed away by the breaking of a *band* near the Left Wing and remained in the river for a fortnight before it could be recovered. Fortunately it was found to have sustained no serious injury. The season was generally unfavourable for the native workmen, who collapse with cold and are unable to work in wind or rain.

When the diversion was completo the Weir wall was built on the part left dry. By the 1st April the ashlar floor was finished from bank to bank, as well as the wall up to the height intended.

The up-stream apron was formed by putting in the clay puddle, as shown in the Section *Plate* VIII. and covering it with 2 feet of kankar pitching, which brought it to the height required for this season.

The talus was laid to a width of 100 feet and formed in accordance with the section on *Plate* VIII. The continuous concrete wall shown in *Plates* VII. and VIII. was put in, and the top of the slope, between it and the edge of the floor, was covered with specially large blocks of kankar set in rough mortar.

Owing to the fact of the cold weather stream flowing over the Weir in this season, instead of through the Weir Sluices as it should have done, a good deal of extra work was necessary to maintain communication across the river. When the works were first opened for the season there was a small side stream passing the Sluices. A short length of pile-bridge was put up to pass this, as the trestle bridge had been removed from the Weir Sluices.

Then the main pile-bridge had to be put up over the stream near the left bank, and finally, when the diversion was to be made, the trestle bridge of last year had to be set up on the talus on that part of the Weir to which the stream was to be diverted.

The end of this working season thus saw the works practically completed. On the Weir Proper there remained only to raise the wall to its full height, an operation which can be performed in the cold weather without difficulty, as the Weir Sluices will then pass the entire supply of the river. The apron would be added to by merely throwing in kankar so as to bring the slope up to the top of the wall after the latter had been raised. The talus would require addition to bring it up to the full section as well as some repairs to make good the effect of scour during floods.

As regards the masonry works they were very nearly complete. What remained to be done could be carried on leisurely during the rains, a very favourable time for building superstructure, the work being now far above the level of the highest floods.

The wrought-iron gates for the Weir Sluices and the Canal Head were prepared in the Narora Workshops during this season. An experimental gate was first made and taken to Dhanauri on the Ganges Canal for trial. The escape dam on the Ratmū offered the means of imitating exactly the conditions at Narora and the gates were fitted and tried there very satisfactorily, only a few trifling alterations being found necessary. Great care was taken in designing these gates to provide against their being set fast by silt lodging in front of them.

Friction rollers are placed at the back of the gates and the principle of an "inclined face" applied to diminish the effort required to open them.

APPENDIX.

Table of quantities of some of the principal items of Estimate; taken from Revised Estimates Part III. of Lower Ganges Canal Project.

Name of Work.	Earthwork.	Concrete.	Brickwork.	Ashlar.	Block kankar.
Left Wing Wall, ..	291,200	48,598	96,211	2,022	40,500
Weir Proper, ...	14,016,000	794,967	1,236,557	185,606	1,900,172
	*2,000,000	†54,587	..	..	‡495,100
Weir Sluices, ...	2,592,500	358,786	626,649	92,197	476,880
	..	..	..	..	‡332,000
Canal Head, ...	1,130,200	84,817	198,119	22,442	90,884
	*120,000	..	..	..	‡150,000
Lock, ...	886,400	57,853	178,660	528	..
Totals, ...	21,036,300	1,399,607	2,336,196	302,795	3,485,536

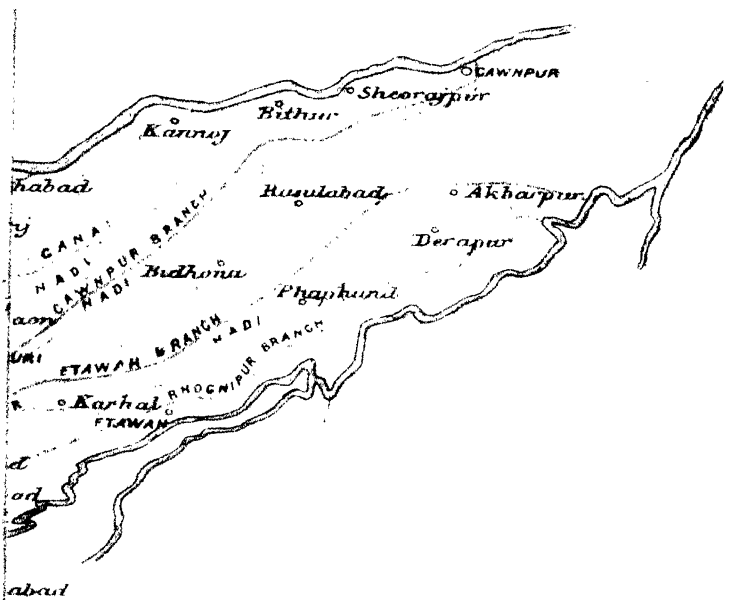
* Clearing Wells. † Dry Concrete ‡ Protective Works.

Cost of the Weir and Head Works about Rs. 33,00,000.

[I wish to acknowledge my obligations to Lieut.-Col. H. A. Brownlow, late Offg. Secy. for Irrigation to Government N. W. Provinces, for kindly furnishing me with copies of Proceedings of Government N. W. Provinces and other printed papers relating to the subject of this Paper. Also to Major W. Jeffreys and Capt. J. H. Western for information relating to the progress of the works since I resigned the charge of them and for their kindness in furnishing me with Plans.]

H. H. J.

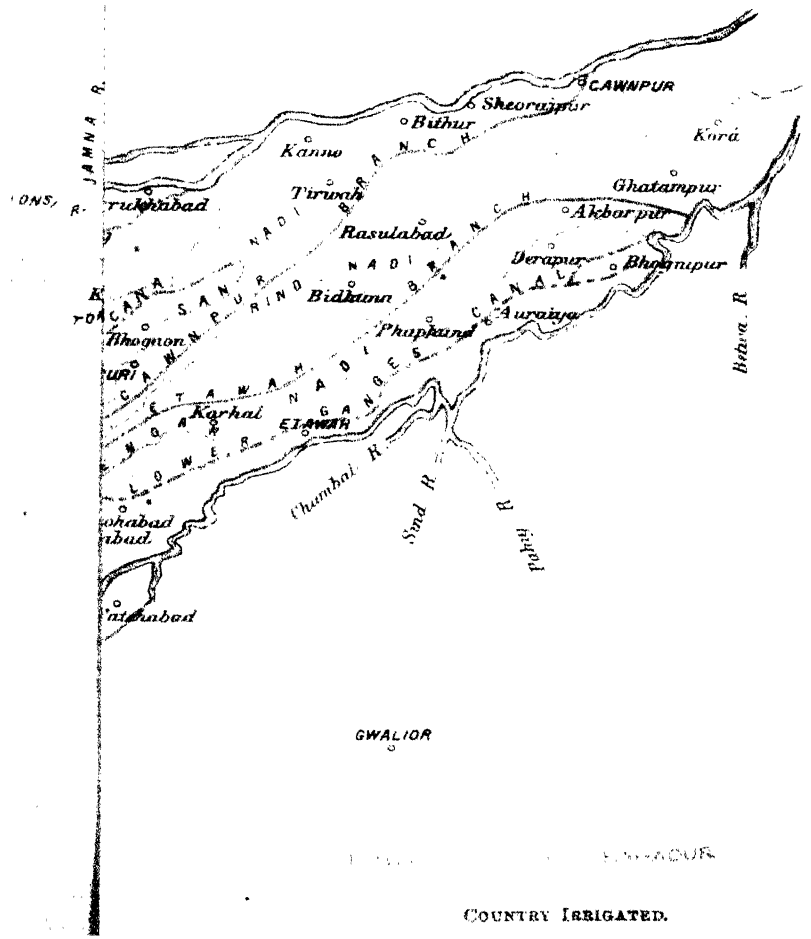
CHATHAM,
27th March, 1878.



COUNTRY IRRIGATED.

By Ganges Canal, ... *Red*
By Eastern Jamna Canal, ... *Yellow*

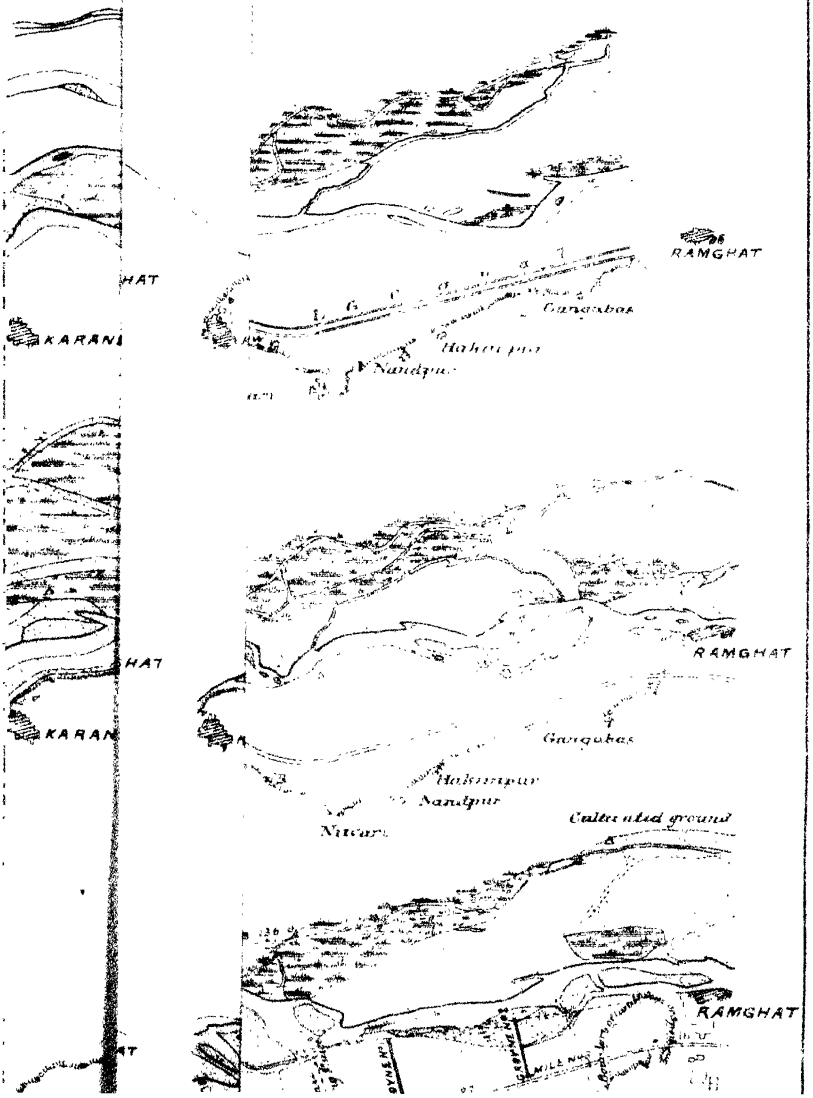
NOTE.—It is not meant that all the country coloured is actually irrigated. The scale is too small to


CAWNPUR
Sheorajpur
Buthur
Kanoo
Kora
Ghatampur
Akbarpur
Rasulabad
Derapur
Bhognipur
Bidhunn
Phuphund
Auraiya
Bhagnon
Karhal
Chumbal R.
Sind R.
Pahuj
Betwa R.
GWALIOR
COUNTRY IRRIGATED.

CANAL,

s showing Ch

. 4 inch = 1



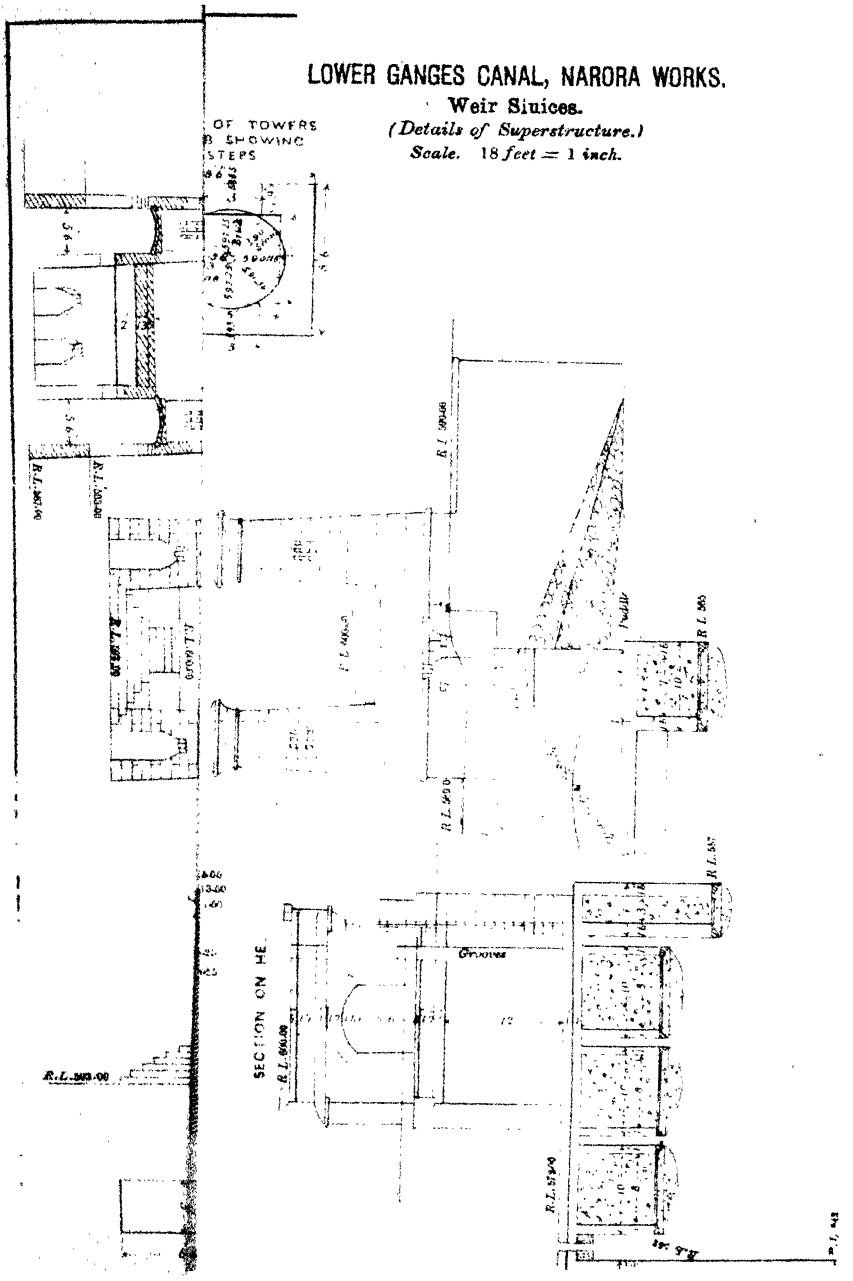
AB

LOWER GANGES CANAL, NARORA WORKS.

Weir Sluices.

(Details of Superstructure.)

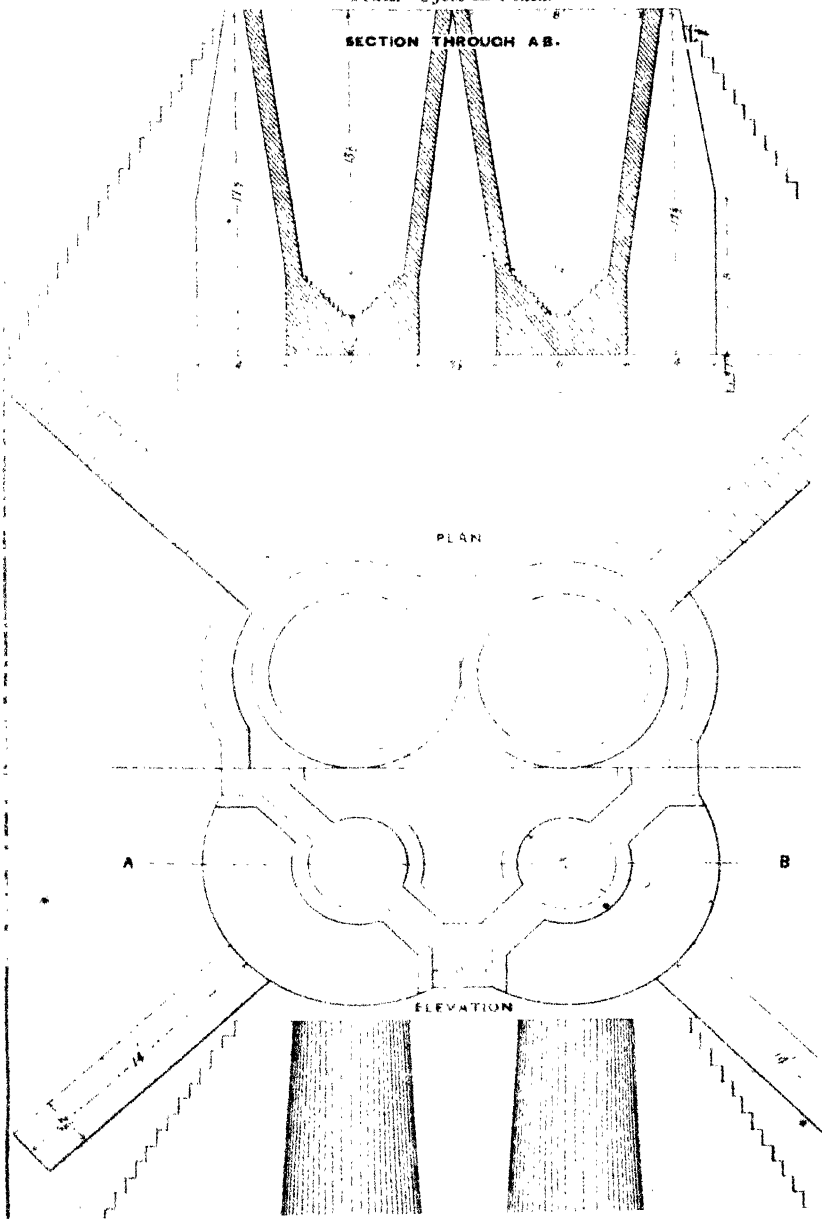
Scale. 18 *feet* = 1 *inch.*



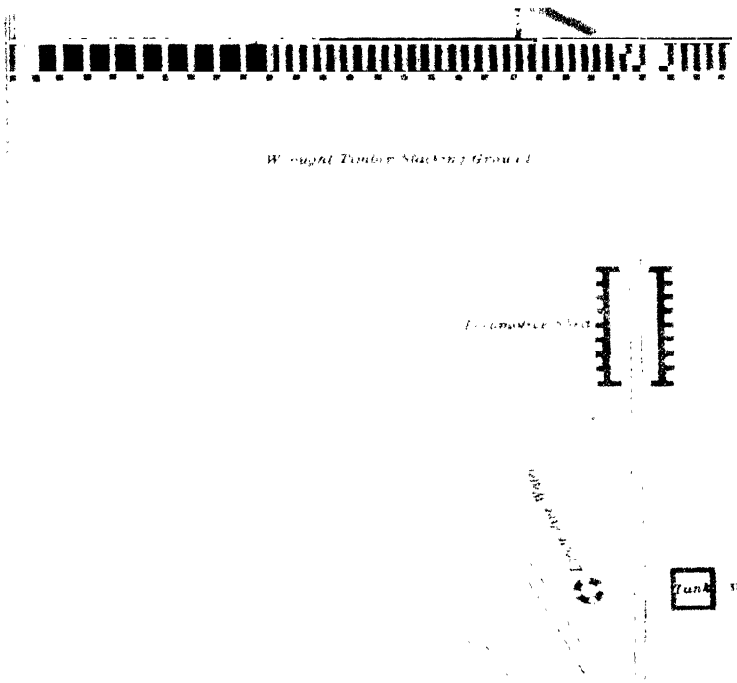
LOWER GANGES CANAL, NARORA WORKS.

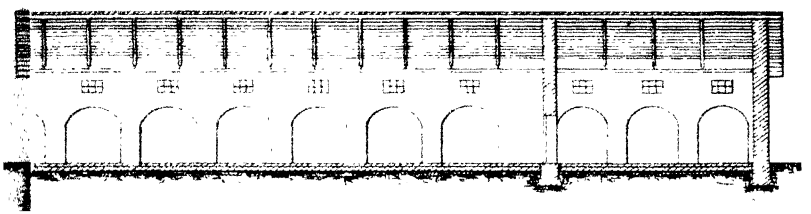
(Lime Kiln)

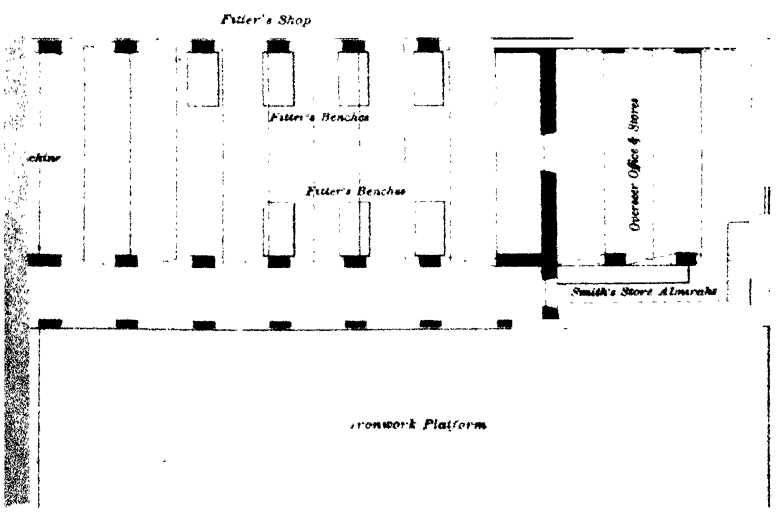
Scale. 8 feet = 1 inch.



West Division Store Yard



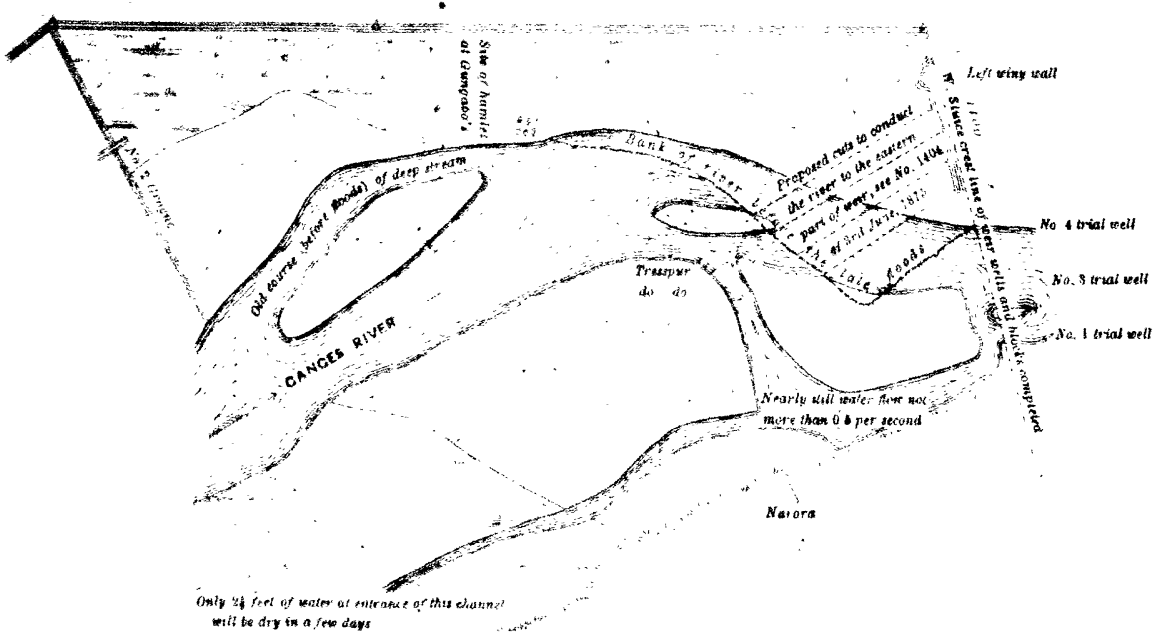



Fitter's Shop
Fitter's Benches
Fitter's Benches
Overseer Office & Stores
Smith's Store & Imprests
ironwork Platform

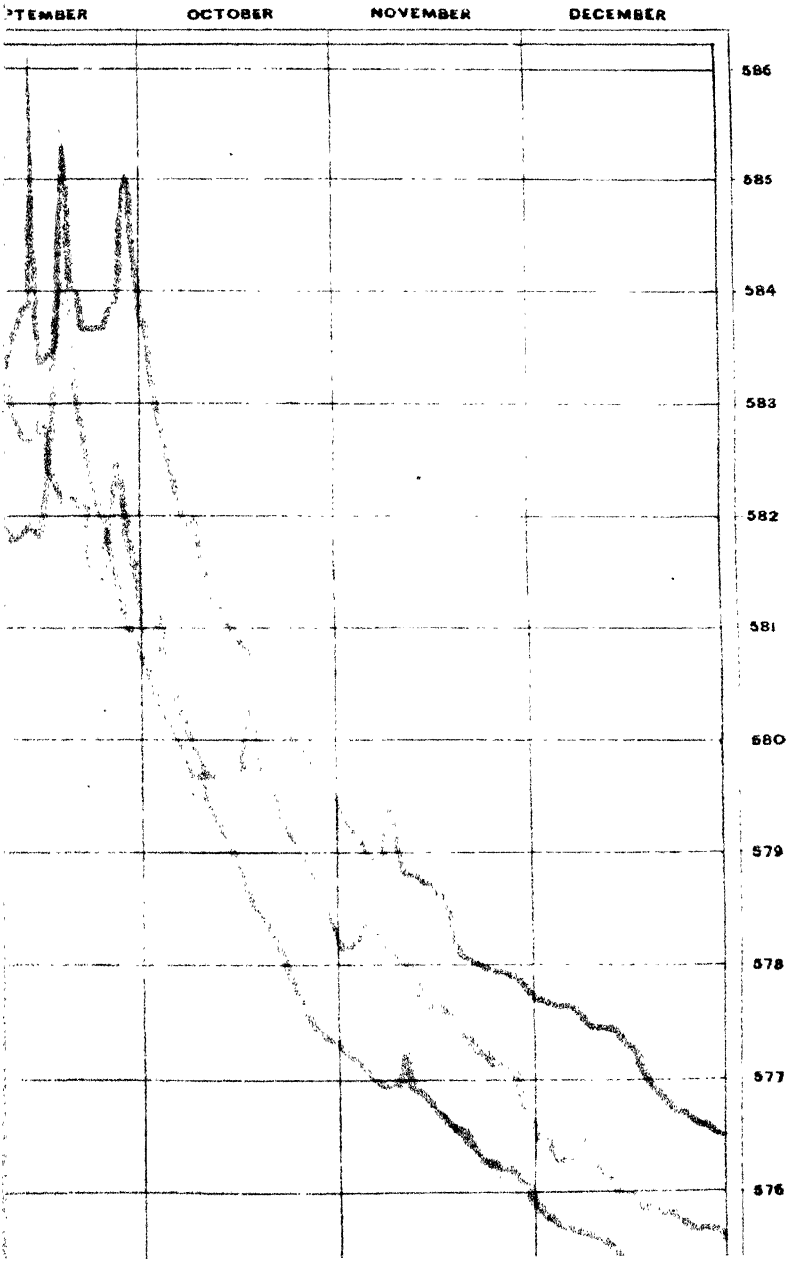
LOWER GANGES CANAL, NARORA WORKS.

State of River 1878.

Scale. 2 *inches* = 1 *Mile*



PLA


PTEMBER
OCTOBER
NOVEMBER
DECEMBER
586
585
584
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576

No. CCLXXIV.

ON A METHOD OF LOADING OR UNLOADING A TRAIN WHEN IN MOTION.

[*Vide* Plate.]

By Capt. W. Sedgwick, R.E., *Tempy. Depy. Consulting Engineer.*

The object of this Paper is to explain a proposed method of communicating with trains in motion so as to enable a through train to pick up or drop from time to time at points along its route passengers or consignments of goods without stopping.

In railway travelling about one-third of the whole time spent in a journey is ordinarily lost in stopping* at intermediate stations.

A small number of stoppages in long journeys are obligatory, for example —at engine changing stations on all railways and at stations where other trains have to be crossed on railways with single lines. However an allowance of one-twelth of the time spent in running would be ample to cover all time necessarily lost by unavoidable stoppages and by reduction of speed in passing through stations at which no stoppage is made. Hence if a through train could drop or pick up passengers and consignments of goods at intermediate stations without stopping and thus perform its journey without stopping except at engine changing stations or crossing stations, not only would the carrying power of railways be increased by one-third but also the consumption of fuel would be reduced by about one-fourth, the same amount of traffic could be carried with a much smaller amount of rolling stock, and the wear and tear of the rolling stock would be greatly diminished because the rolling stock would be saved from most of the blows and strains to which it is now subjected whenever trains are

* In time lost in stopping, must be included the time lost by slackening speed before the train actually stops and also after the train starts again the time lost before full speed is regained, in addition to the time lost by actual detention at the station.

started or stopped: and thus both the duration of all journeys and the fares charged for them could be reduced by fully one-fourth. The subject is therefore one of no small importance to the public as well as to Railway Companies.

Now, it is quite plain that if two trains were running side by side on two parallel lines of rails at the same speed and in the same direction, and if a hinged platform were let down from one of the trains on to the other, so as to bridge the space between them, passengers in any number could be transferred from one train to the other without any necessity for stopping the trains. For they could step across from one train into the other as easily as they can move from one side of a carriage to the other when a train is in motion. Similarly, the passengers' luggage and any consignments of goods, if loaded before hand on trucks with wheels, could in like manner in a few seconds be transferred from one train to the other.

If therefore a second line of rails or a siding were laid down alongside of the main line for a short distance at points where through trains were required to drop and pick up passengers, and if trains of two or three carriages or wagons, or, as we may call them, station trains, were run out from these points alongside of the through trains, for a short distance, as they passed, the through trains would be able to drop and pick up passengers without stopping. The station trains would of course carry out to the through trains the "outwards" and bring back the "inwards" passengers and goods.

To work the station trains by steam power would doubtless be a very expensive arrangement. However steam power will not be required if the ends of the siding laid down for the station trains are curved outwards until thay are clear of the roadway of the main line and then carried up inclines with sufficient fall. For then a station train in descending the incline, at the end of the siding nearest to an approaching through train, will acquire, by gravity, sufficient velocity to lay itself alongside of the through train when it reaches the siding with a slightly reduced speed. When the two trains are fairly alongside of another and going at the same speed the station train can be made fast to the through train and then if the through train goes ahead at full speed it will take the station train to the other end of the siding and leave it with sufficient way on to be able to run by itself up to the top of the incline. There, when unloaded, it will be ready to take another load out and to serve the next

train in the opposite direction in the same way as it served the first train. When two trains follow each other from the same direction without any intermediate train from the opposite direction it will be necessary either to have two station trains which can be worked either together or separately or to run the one train back by gravity to the other end of the siding and hand-shunt it up the incline before the second through train arrives.

The outlines of the scheme having been thus explained we may proceed to discuss the details.

A body in vacuo whether falling vertically or descending an inclined plane without friction acquires a

velocity $= \sqrt{2gh}$

where $g = 32{\cdot}2$

and h = the vertical height through which the body descends whether falling freely or descending an inclined plane without friction.

Hence if a train were to descend in vacuo without friction an incline with a fall of one foot it would have acquired on reaching the bottom, a velocity of about 8 feet per second, equivalent to $5\frac{1}{2}$ miles per hour; also if it descends an incline with a fall of 4 feet it will acquire a velocity of about 16 feet per second, equivalent to 11 miles per hour; similarly, if it descends an incline with a fall of 8 feet it will acquire a velocity of about 22·7 feet per second, equivalent to $15\frac{1}{2}$ miles per hour. And so on.

Now, though the actual velocity acquired by a train descending an incline with friction and exposed to the resistance of the wind will be far short of the theoretical velocity in vacuo without friction, still making full allowance for the resistances of wind, friction, curves and inequalities in the road, &c., it is plain that banks of very moderate height will give inclines with enough of fall to give station trains, when descending them, sufficient velocity for all practical purposes, more especially on Indian Railways where the speed seldom exceeds thirty miles an hour and is reduced at stations owing to the lines being generally single and to the consequent employment of facing points, to five miles per hour.

With regard to the length of siding required for the station train. If we assume that the speed of the through train, at the point where the station train comes alongside of it, is five miles an hour and at the point where the station train is cast off is twenty miles an hour, then the aver-

age speed during the time the two trains are alongside of one another would be about twelve miles an hour.

When the trains are alongside of one another the passengers, whether leaving the through train or joining it, will have merely to step across from one train into the other, the purchase and examination of tickets, search for places, arrangements for refreshments, &c., being made at leisure upon the through train. Also all luggage and consignments of goods to be transferred from one train to the other will be arranged before the station train comes alongside, on trucks with wheels, which will merely have to be run across from one train to the other, the examination, labelling, weighing and stowing being all done upon the through train at leisure. It will therefore only be actually necessary for the station train to be alongside of the through train for a few seconds. Supposing that two minutes were the time allowed for the trains to be alongside of one another as a maximum under any circumstances, the length of siding required would then be 2000 feet or about the same length as is now allowed for station sidings on broad gauge lines. Two thousand feet of siding would, under ordinary circumstances, probably be amply sufficient even if the through train were to run past the siding at an average speed of twenty miles an hour.

The *Plate* shows the proposed arrangements for working on a railway with a single line of rails. As has been already explained, the speed of a train, on such a line, when passing through the facing points of a station siding, must not by regulation exceed five miles per hour. The facing points are always at the end of a station siding nearest to an approaching train. It will be noticed that the ends of the station siding are curved outwards from the points, for a length of 200 feet by curves to a radius of 1500 feet so as to clear the roadway of the main line, they are then run straight and carried for a length of about 125 feet up inclines of 1 in 25. After passing the inclines the ends of the siding are carried on a level to the waiting sheds and goods' sheds. For these, small buildings will ordinarily be erected at both ends of the siding. At large stations however and generally at all places where the fact of the arrival and departure platforms being about half a mile distant from each other would cause inconvenience, the ends of the siding would be curved inwards beyond the inclines so as nearly to meet and in such case one waiting shed and goods shed only would be provided.

In the fore-part of each of the through trains, *i. e.*, immediately behind the tender of the engine two or more platform wagons are provided (*vide Fig.* 3). These platform wagons have sides about 4 feet high and wells between the wheels; they are roofed over with flat roofs and the tops enclosed with posts and swing rails, so as to enable passengers to pass across them into the carriages in safety. Hatches are provided in the roofs of these platform wagons, so as to enable heavy baggage and consignments of goods to be stowed away in them or got out from them when necessary. During the hot season and in the rains the platform wagons are provided with temporary roofs.

The carriages will have end openings and will be connected together by bridges so that passengers can pass from one end of the train to the other.

Where end openings are not practicable platforms running outside of the carriages on brackets will have to be provided; the ends of these platforms would be connected by bridges. The front carriage of each train would be reserved for an office where tickets would be obtained and luggage weighed and labelled. Refreshment and ablution carriages for all classes would accompany each train, making a long journey.

Station trains would be composed of platform wagons similar to those on the through trains, they would however be covered in on three sides and provided with powerful brakes.

The station trains would be worked in the following way:—A short time before the arrival of a through train was expected all passengers wishing to travel by it would be got on to the station train at the end of the siding nearest to the approaching through train and at the same time the passengers' luggage and any outwards parcels or consignments of goods for the through train would be piled on trucks with wheels at one end of the station train. As soon as the station train is loaded it will be hand-shunted out to the nearest incline and the wheels there scotched. The station train must be run right out on to the incline so that it may start off, by gravity, directly the scotches are knocked away from the wheels. When there is a strong head wind the train must be started from the top of the incline but when the wind is aft it can be started half way or even further down the incline.

As soon as the through train arrives at a point, previously determined by experiment and marked by a large disc by day and by a light by night, the scotches will be knocked away from the wheels of the station train,

and the station train will descend the incline by gravity and acquire in its descent sufficient velocity to be able to run along side of the through train as it reaches the siding with speed slackened to the speed fixed by regulation for a train when passing through facing points. When the speed of the station train is greater than that of the through train the guard of the station train reduces the speed of his train by using the brake. As soon as the station train is along side of the platform wagons of the through train, and the trains are going at an uniform speed, the guard of the station train makes his train fast to the through train and lowers a platform so as to connect the two trains and hands the guard of the through train the necessary line clear report for his onward journey. The passengers who are leaving or joining the through train step across from one train on to the other and the trucks of luggage and goods previously loaded are wheeled across from one train to the other. The driver of the through train, as soon as he has satisfied himself that there will be no hitch, goes ahead at full speed and the guard of the station train when his train approaches the end of the siding casts off the lashing connecting his train with the through train and allows his train to run up the incline at the end of the siding, where he then unloads it.

Water and fuel can be supplied to the locomotives of the through trains by water tanks* and fuel boxes on wheels run out and taken off from time to time by the station trains, in the same way as loads of luggage or goods are brought out or taken off on trucks with wheels by the station trains.

Self-acting lubricating arrangements must be supplied to all parts of the machinery of locomotives: the tires of wheels will be examined from time to time at engine changing stations.

The condition of the wheels could be examined periodically and oil could be supplied when necessary to the axle boxes if a platform were provided for the purpose outside the carriages running the whole length of the train on either side. If the carriages had side doors and access to them were obtained by outside platforms, in the manner already described, additional platforms, for examining the wheels, would not be required. In case of a train being full the guard of the station train of the previous station would announce the fact by telegraph to the next station so as to prevent passengers being embarked on the station train.

In conclusion, it may be pointed out that in addition to saving time and

* The water tanks if necessary can be fixed to the platform wagons of station trains and water run from them by a hose into the tenders of the locomotives.

expense in working, the adoption of an arrangement of this sort would add greatly to the comfort of all classes of travellers; it would enable seats to be paid for and luggage to be weighed and labelled at leisure; it would enable passengers to choose their own company; it would enable arrangements to be made by which passengers of all classes could get their meals and be able to wash and dress themselves in comfort, it would do away with the necessity for the frequent examination of tickets, and lastly, it will enable the number of places, along a line, where passengers can be dropped or picked up to be increased indefinitely without causing any appreciable delay. For if the inclines of the sidings were given sufficient fall, as they easily might be, to impart a speed of twelve or fifteen miles an hour to the station trains and if no points and crossings were put in (they would only be required at crossing stations) the through trains, in running past the stations, would only require to slacken speed sufficiently to pick up the station trains.

It would doubtless take guards some little time in getting accustomed to working station trains in the manner proposed, but there could hardly be any real difficulty more especially if they had to deal at first with trains going at five miles an hour only. It any hitch were to occur the driver of the through train could bring his train to a stand and drop and pick up passengers in the ordinary way.

The adoption of this method of working small stations would not prevent trains from stopping when necessary at large stations.

It may sometimes be necessary, in order to avoid the introduction of facing points in the station siding, to have the station siding, altogether clear of the crossing siding. To effect this the station siding will be laid without any points and crossings and the crossing siding will be put in on the opposite side of the main line.

To guard against the possibility of accidents arising from the use of lashing to connect the station train with the through train, from neglect, on the part of the guard of the station train, to cast the lashing off when the station train gets near the end of the siding; the following way of connecting the trains can be employed:—Stout catches are hinged on to points on the platform wagons of the station train and when the station train comes alongside of the through train these catches are dropped between two light spring buffers fixed at corresponding points on the side of the platform wagons of the through train. As long as the station train

runs on the portion of the siding where the line is parallel to the main line the catches bear against the buffers on the platform wagons of the through train and the station train is carried along by the through train. But when the station train reaches the curve at the end of the siding the divergence of the train draws out the catches from between the buffers and the trains separate.

It should be remarked finally that the object of this proposal is to enable Indian Railways more fully to meet the wants of the Indian Public. In India even in the most densely populated districts the population is scattered in villages and not collected as a rule in large towns. Consequently to serve any district properly a railway must have stations at very short intervals.

But on the other hand, each stoppage must cause a considerable reduction in through speed. And it is impossible to make up for loss of time from stoppages by quick running between stations, because quick running is incompatible with cheap working, and cheap fares are an absolute necessity in a poor country such as India is. Hence, unless some arrangement of the sort proposed is introduced, the number of stations on lines of railway must be limited, and the country continue as at present to be indifferently served.

W. S.

5th February, 1878.

A PROPOSED METHOD OF EMBARKING AND DISEMBARKING PASSENGERS AND GOODS.

ON OR FROM

Trains in motion.

FIG. 1.

PLAN OF SIDING

Scale 600 *feet* = 1 *inch.*

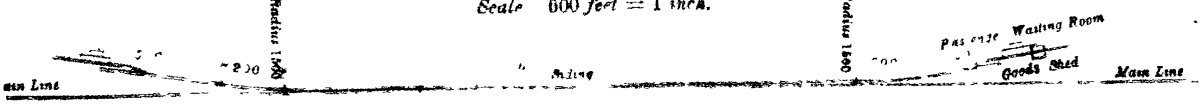


FIG. 2

LONGITUDINAL SECTION OF SIDING

Scale for Horizontals 600 *feet* = 1 *inch.* *Scale for Vertical* 60 *feet* = 1 *inch.*

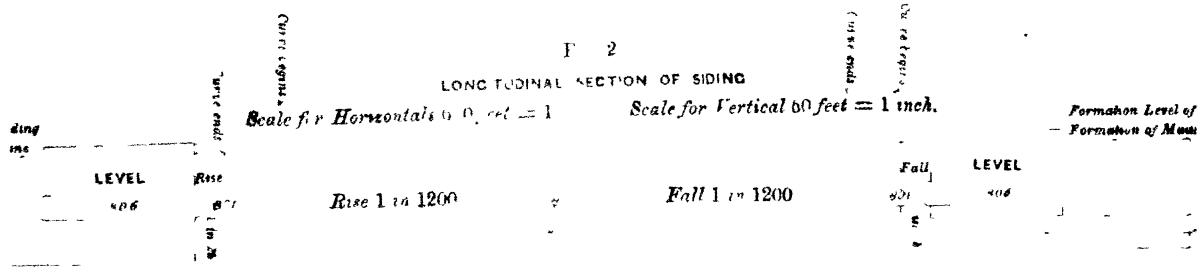
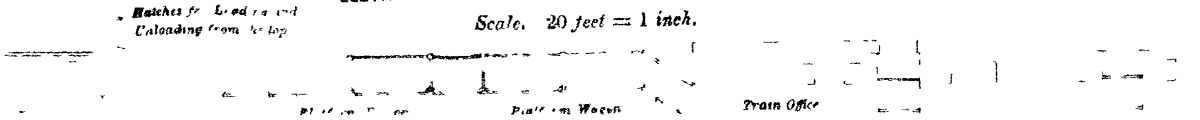


FIG 3

ELEVATION OF FORE PORTION OF A THROUGH TRAIN.

Scale. 20 *feet* = 1 *inch.*



No. CCLXXV

THE EKRUK TANK.

Communicated by Chief Engineer for Irrigation Bombay.

Dated Poona, 20th Feby., 1878.

THIS work, situated about 5 miles north-east of the town of Sholápur, is one of the largest of its class undertaken by Government in this Presidency. The site was selected by Colonel Fife, R.E., in 1863, and the scheme, as drawn up by him, was submitted for the sanction of the Government of India in 1866. The work was commenced in 1866-67.

The tank or reservoir is formed by a dam 7,000 feet in length, and 76 feet in maximum height, thrown across the valley of the Adhila River, a tributary of the Sina, at a point above which the catchment area is 160 square miles. The level of full supply is 16 feet below the top of the dam. The escape of flood-waters after the filling of the tank is provided for by waste weirs excavated at each end of the dam. That on the right bank is 300 feet long, and its crest is at the level 3 feet higher than that of the right bank weir. There are three canals for irrigation; two take off a level of 14 feet below the full supply-level, in the tank, and are designed for four months irrigation, and the third takes off 39 feet below full supply-level, and is designed to give a perennial discharge.

The dam is entirely of earth. The top width is 20 feet in the central or highest portion, decreasing towards the ends where the head of water is less. The water face has a slope of 3 in 1 below highest flood level; above that level the slope is steepened and assumes the form of a curve. The back slope is 2 in 1. A puddle trench, 15 feet wide at bottom and varying in depth from 8 to 20 feet, is provided along the centre line to cut off leakage under the dam, but there is no puddle wall, the

whole of the material of the dam being of good soil, laid in layers 3 inches in thickness, and watered and rammed or rolled. The dam has a coating of muram to protect the slopes and top from the weather, and the slope on the water side is pitched to protect it from the waves.

Where the dam crosses the river and its height is greatest, a second parallel puddle trench 15 feet wide is added 50 feet from the toe of the inner slope for greater security against leakage through the substrata.

Both the puddle trenches are carried down to an impermeable stratum.

The dam was closed in December 1869, and the tank filled the following monsoon.

The tank, when full, has an area of 7¼ square miles, and contains 3,350 millions of cubic feet.

The work is designed principally for irrigation, and partly for water-supply of towns.

In 1872, a flood occurred, which rose to within 7 feet of the top of the dam. The maximum head of water to which the dam has been exposed is thus 69 feet. The minimum and maximum head of water each year, that is, the head during greatest rise, and before the first replenishment at the beginning of the monsoon, has been—

	Maximum head. Feet.	Minimum head Feet.
1870	23	56
1871	38	49
1872	42	69
1873	48	53
1874	44	63
1875	49	60
1876	43	56
1877	37	59

The dam is in excellent order, and has never given cause for the least uneasiness. There is no leakage whatever, though, as might be expected, there are springs in the ground some distance in rear of the work, but even from them the discharge is slight. In February 1878 the total leakage gauged below the dam was 0·50 cubic feet per second. At this time the head of water in the tank was 55 feet. The discharge gauged comprises the whole of the springs which are led into the river by formed drains.

These remarks are made as introductory to the following

dence relating to the construction of the work, which is printed at the suggestion of Colonel Merriman, as it will prove of general interest to the Department.

W. C. H.

To—*Capt. Penny, R.E., Exec. Engr. for Irrgn., Sholápur.* From—*Lieut.-Col. J. G. Fife, R.E., Chief Engr. for Irrigation.* No. 779 *of* 1868.

Dated Poona, 16th May, 1868.

Sir,—Having made an examination of the Ekruk Tank dam, I have the honour to state the results, and to make some observations for future guidance in completing this very large, and in some respects, difficult work.

The trial pits sunk into the dam earthwork show that the plan of laying down the material in 3-inch layers, and rolling it, has prevented large lumps of earth remaining unbroken, and as far as can be judged from the present depth of the pits (from 3 to 4 feet), the material at a slight depth below the surface is compact and damp. Near the surface, it was too dry to crush completely under the roller, or to become very compact without moisture. The nodules of clay were very small certainly, but the extreme dryness of the weather has prevented them from adhering to each other, and though the work is good as far as density goes, it wants adherence of the particles of earth. When the pits are sunk deeper, I request you will report the state of the material below what was exposed to view to-day.

The material used for the dam is very good, when of a good clayey nature, for checking leakage, but I think that for the upper part of the dam, where it will be exposed to the drying effect of the air after each monsoon, it should have a larger admixture of sand, or small pebbles, or kankar nodules, to prevent cracking, and, in completing the work, this should be borne in mind, and the material used should be either selected or mixed with a fair proportion of sand or pebbles. In the heart of the *band*, the material you are using is excellent. It has a sufficient quantity of sand and kankar nodules to prevent cracking, as it will never become thoroughly dry. I mention these points, with respect to the nature of the material, that no precaution against accident, or even slight injury to the work, may be overlooked. I did not observe any cracking of the material used for the body of the dam (the puddle trench excepted,

which I will presently notice), and I noticed that you have already covered the completed portions of the *band* with a layer of muram or gravel, to give the material a better consistency to bear the action of the weather. The portion of the dam yet to be completed is, however, the central part where the height is greatest and where, from the great mass of material employed, there will be more liability to cracking, and the material should therefore be selected and laid down with still greater care.

I now come to the subject of the puddling. I shall first speak of the material, and then of its application to the work. The material hitherto used is, I think, too pure a clay. More sand or fine gravel or small kankar nodules should be mixed with it to prevent cracking. It may be said that in the deeper parts of the work, where the puddling is as much as 28 feet below the natural surface of the ground, the clay cannot dry, and therefore cannot crack, and considering the difficulty and expense which have been incurred in keeping the water down in the trench, it is impossible to gainsay this, but still I think that the material would pack better had it a little more sand, and at the same time it would not lose its stanching property as a clay. It is not like the clay which is commonly used in England for puddle. It is more soluble in water, and requires peculiar treatment, as we decided last August, when I examined the work with you. It does not answer, as we then saw, to use much water when ramming it.

Two methods of packing the puddle have been tried, one with water added to the material, and the other without any addition to the moisture the material possessed when excavated from the pits, and the result at the two spots examined this morning was the same. After removing about one foot of the surface stuff which had cracked from exposure, the material was found free from flaws, and of about the same density in each case. As to the degree of moisture which will be found most convenient, I will record my opinion that I think there should be just enough to make the material plastic under the stroke of the rammer. If the material is very wet, it either adheres to the rammer or springs under the blow, and cannot be made so firm and compact as when used in a drier and tougher condition.

With respect to the application of the material, I think, as I have already mentioned, that a little sand added to the clay or, as you have yourself suggested, a clay obtained from some of the pits, which show

a greater proportion of sand and kankar nodules, would be an improvement. I think you would find it easier to render compact, and as the puddle wall rises above the level of the ground it will not crack.

The trench you have excavated across the valley, and which is already 14 feet below the bed of the stream, the lower 11 feet being through muram which at bottom of trench is quite hard, is I consider quite deep enough, especially as the water which finds its way into the trench appears almost everywhere to issue from the upper strata, and not from the bottom of the trench. The trench should be filled with puddle before the monsoon, and the whole covered over, as you propose, with stone pitching to prevent the scour removing any of it. The pitching should be rather below the natural bed of the stream, and not upon it. While the trench is being filled, the pumping should be continued night and day, that the water may be kept down, and the material packed and rammed as tight as possible.

The second parallel puddle trench should also be completed in the same manner before the monsoon if possible—at any rate the portions of it in the river channel and branch channel should be completed. The higher portions across the island, and on either bank of river, may be done after the monsoon.

The third parallel puddle trench which we contemplated making some time back under the rear slope of the dam is not necessary, and may be omitted, as the muram substratum has proved more water-tight than was anticipated, and whatever leakage does occur under the first two puddle trenches may be allowed to find its way down the river channel.

With respect to the removal of sand from the river bed under the whole base of the dam, which you have been carrying on for some time, it will be satisfactory if you get it done, and the sand replaced by good water-tight material, before the monsoon, as at its conclusion you will be able to resume the work, and finish the dam without delay; but I would not excavate the sand anywhere unless you are sure of getting the places filled again, otherwise the first flood may bring down as much sand as you remove, and the first outlay will be thrown away. I may mention that the sand and muram excavated in the river bed may be advantageously used for the rear slope of the dam, and for filling in the river channel immediately below the dam. Some leakage there is sure to be, and if you have an insoluble material to receive it, and permit of its passage

clear away from the dam, the toe of the rear slope will be kept dry, and there will be less settlement.

P. S.—The above letter has no reference to the points alluded to by * * * * * * who is clearly not aware of the nature of the work under execution at the Ekruk Tank. The mode of construction is very similar to that successfully practised by Mr. Thom, the only difference being that we have our material ready mixed before we lay it on the dam, and for reasons of our own, we have also excavated deep into the muram substratum to prevent underground leakage as much as possible.

As to the expression "puddle" if it be taken to mean stuff worked up with water till it is in a soft slushy condition we do not use it; but if its meaning be a compact and impermeable wall of clayed material we certainly do use it; but instead of making a thin wall above the level of the ground, distinct from the body of the dam, though carried up simultaneously with it, we make the whole body of the dam of puddle. Perhaps, taking the literal meaning of the word, we do not use puddle, but the intention or object of the puddle when made up into a wall we do fully carry out by a different mode of applying good material, and a more liberal use of it.

MEMORANDUM.—No. 32A *of* 1868.

Dated Mahableshwar, 4th June 1868.

On receipt of Memo. forwarding the remarks of * * * * * * on the Ekruk Tank, I referred the subject to Capt. Penny, who is in executive charge of the works, and I then proceeded myself to Sholápur to form my own opinion.

I beg to submit two reports on the subject by Capt. Penny, the first giving a description of the material used and the mode of applying it; the second showing the result of several trial pits which at my request were sunk through the dam. I saw these pits myself sunk to a depth of from 3 to 5 feet, and was satisfied with the result; but I requested Capt. Penny to sink them much deeper and report the result, which he has accordingly done. The fact of these pits having been sunk in the fresh earthwork to a depth of from 12 to 17 feet without the discovery of any lumps, and without the aid of shoring, the sides of the pits standing perpendicular without aid, speaks for itself. The very dryness of the material, though

apparently a fault, only shows more evidently the goodness of the work, for the want of adhesion of particles to each other, which Capt. Penny mentions, must have caused the sides of the pits to fall in had the material not been well consolidated.

The work which has been recently examined will have the advantage of a year's weathering (including the approaching monsoon) before it is exposed to the water, and the only point relating to this part of the subject, to which I considered it necessary to direct Capt. Penny's attention, was that he should observe the state of the material as it is brought to the dam during the fair season, and see that it does not get too dry before the rollers are passed over it. I should mention that either Capt. Penny himself, or his assistant, Mr. Parry, constantly resides upon the spot.

There is puddle trench from one end of the dam to the other, to cut off leakage through the ground beneath the dam. In the lowest part of the valley, it is 14 feet deep below the very lowest spot, and in other places the depth is greater. Great difficulty was experienced in carrying this trench down, and pumping operations have been going on night and day for months, and it was for some time feared that the operation would not be successful without a heavy outlay, and the employment of steam power. I was glad to find on my recent visit that the strata in which the springs occurred had been cut through, and a good substratum exposed, and I therefore ordered the filling up with puddle to be commenced, and I believe it is now completed.

With respect to the mode of using puddle, it is the practice in England to add a great deal of water till the stuff is brought into a sloppy condition. However, the treatment must depend somewhat on the nature of the material. The strong yellow clay commonly used for the purpose in England, takes up water very slowly, and it is difficult to make it too soft or slushy, but with the Dekkan soils I do not approve of so much water being used. At Ekruk I examined two portions of the puddle trench which had been made with and without additional water, and exposed to the monsoon, and they were both compact, only a small quantity of water had been added to make the material plastic under the stroke of the rammer. At Pashan, last season, I found that too much water was being used, and I directed its discontinuance.

In the dam itself or what is above ground level, a puddle wall is not used at Ekruk. I prefer the mode of consolidating the *whole* of the

earthwork at Ekruk, to trusting to a thin puddle wall with inferior work beside it. From all I have been able to ascertain of the Sheffield disaster which occurred some years ago in England, I believe it was this reliance on the puddle wall which was the cause. A slender puddle wall of great height may be rent by the unequal settlement of the adjoining material, and unequal settlement there will be, unless the whole dam is carefully consolidated, or kept in a wet condition by the climate from the very first, when the action of the moisture remedies the want of consolidation. If a rent occurs in the puddle wall the leakage is concentrated on one spot, and may blow out the material from the back of the dam. In India, puddle walls are but rarely used, and only by engineers who have received their education in England. I should be very sorry to trust to a puddle wall and material laid down in thick layers as mentioned by some English engineers—*vide* extracts given in Capt. Penny's report. I prefer a complete and uniform consolidation of the whole thickness of the dam by the application of thin layers (which ensure both the breaking up of lumps and admixture of different soils), and by systematic rolling or ramming.

J. G. F.

To—*The Chief Engineer for Irrigation, Poona.* From—*Capt. C. B. F. Penny, R.E., Exec. Engr. for Irrigation.*

Dated Sholapur, 12th May, 1868.

Sir,—In reply to your endorsement No. 4A of the 5th instant, forwarding copy of letter No. 2527 of the 23rd ultimo, from * * * * * * * * * * and requesting my report on the same, I have the honour to state as follows:—

* * * * * calls the attention of Government to [ ] what he assumes to be the faulty construction of the Ekruk Tank *band*, which he states is being constructed "of the ordinary earth dug in the neighbourhood without either masonry or puddling."

This statement [ ] is likely to mislead Government as to the nature of the ordinary earth dug in the neighbourhood of the *band*; as to what "puddling" consists of; and must also give Government the idea that the whole subject of the construction of the *band* has been considered by the Irrigation Engineers in the most superficial manner. I would therefore briefly describe the nature of the "ordinary earth dug in

the neighbourhood" of the tank *band*. Next quote some few authorities as to the nature of puddle, and then go into the question of whether the method adopted by us of constructing the *band* was done too hastily, or with undue consideration.

The upper surface of the earth in the neighbourhood of the *band*, for about 1½ to 2 feet in depth, may be called the ordinary black soil met with in the Dekkan, which has all the properties of clay. Below that, and almost to any depth, the soil is a stiff clay, interspersed with lime, which takes the form of kankar nodules or thin layers of fine grains of lime. So thoroughly is this lime mixed with the soil that in vertical sections of the material 12 feet and upwards in depth, although the upper foot or two may have crumbled away, the whole of the remainder has remained upright and sound.

Regarding the proper material for puddle, Professor Rankine says that the best puddle is formed of "clay freed from all large stones, roots of plants and the like, and containing as much sand and fine gravel as is consistent with its holding water; if there is too little sand the puddle is liable to crack in dry weather." Visibly therefore the use of the sand is to prevent the clay from cracking. In our case, *lime* is substituted, and has the same effect. Mr. F. Dobson, C.E., on Foundations and Concrete Works, Weale's Series, says regarding puddle, "Marl when chopped up small, and well punned, answers exceeding well, as also chalk, if the lumps are not too large. The greatest point of importance is to leave no large lumps, but to break up the material very small before using it, and to pun it up carefully so that no vacuities may be left in any part." I will therefore afterwards show that, according to what Mr. Dobson states is the great requisite for puddle, the whole of our *band*, as being constructed, is one mass of puddle in the most approved fashion.

Having therefore the whole requisites for puddle in the ordinary earth dug in the neighbourhood of the *band*, it remains to be seen in what manner the *band* is being constructed.

Professor Rankine says, "that the embankment should be made in thin layers from 9 to 18 inches deep, well ramming each layer before laying down the next." For constructing the Ekruk Tank near Sholápur, the following method has been, and is being adopted :—

A trench* has been dug throughout the entire length of the *band* down

* When the dam crosses the river bed and its height is greatest there are two parallel trenches.

to an impermeable stratum, and this has been filled in with chosen soil, the earth being supplied in layers of 3 inches, and well rammed. In forming the upper part of the *band*, the earth has been spread in the same manner in layers of 3 inches, but instead of being rammed, each layer has been most carefully rolled with iron rollers. The solidity of the embankment is still further increased by all the earth being brought in carts, each layer of 3 inches has therefore an immense traffic of carts over it, besides being rolled, before another layer of 3 inches is placed on the top. By having the earth spread in such very thin layers, it becomes a matter of impossibility for any large lumps to be left in the *band*. So perfect and consolidated is the portion of the *band* already completed that it brought forth the remark from the late District Engineer of the G. I. P. Railway at Sholápur, that "the whole *band* is a puddle wall," or words to that effect. I speak from memory, and the expression is impressed on me from having noted it at the time as a favourable opinion, from a practical man, of the construction of the work.

It should be borne in mind that all acknowledged authorities for the construction of dams, speak on the best method of making *bands* from the experience they have had in England or the Continent, &c. India to all of them is a closed book, and such soil as is found in many parts of India as the ordinary soil of the country, is of the same description as we are told great pains should be taken to obtain, that is, it is composed of clay with lighter material in such proportion as to form the best ingredients for puddle. With soil such as this, the whole of the Ekruk Tank *band* is constructed in layers of 3 inches each; whereas authorities tell us that it is only necessary for a very small portion in the centre of the *band* to be built after this manner, the material for which should be carefully cleared of all large stones, roots of plants, and the like; the remaining portion may be made of clay, but without any clearance of large stones and the like, and constructed in layers of from 9 to 18 inches thick, or as Mr. Samuel Hughes, C.E., says in his Treatise on Water Works, "in layers not exceeding 2 to 3 feet in thickness."

Puddle walls, however, are not always used in making embankments in Great Britain even. Referring again to a treatise on water works by Mr. Samuel Hughes, C.E., page 287, it will be seen "that Mr. Thom of Glasgow, who has had great experience in the construction of these works, (earthen embankments) does not approve of puddle trenches in the bank;

but after excavating the foundation to such a depth as to be firm, and prevent the passage of water, he forms the bank by spreading alternate layers of puddle peat, or alluvial earth, and gravel, beating them well with wooden dumpers till they are completely mixed. He afterwards covers the slopes with a puddle of small stones or furnace cinders, mixed with clay, to prevent moles or other vermin penetrating into the bank." Mr. Thom refers to "many reservoirs he has constructed in this way without puddle trenches at Greenock, Paisley, and elsewhere."

I trust I have shown therefore that the subject of the best method of constructing the Ekruk Tank *band* was not considered hastily, and also have satisfied * * * * * * that the Irrigation Engineers are fully aware of the importance of the work they are carrying out and will have a due regard for the interest of all concerned. * * * * * *

In conclusion, I would wish to add that Mr. Thom's method of covering the slopes with a puddle of small stones or furnace cinders, mixed with clay, can always be adopted should higher authority consider such necessary.

C. B. F. P.

To—*Capt. Penny, R.E., Exec. Engr. for Irrgn. Sholápur.* From—*The Chief Engr. for Irrigation.* No. 778 *of* 1868.

Dated Sholapur, 16th May, 1868.

Sir,—I have the honour to request you will make some experiments with the material you are using for the Ekruk Dam.

A moderate quantity, say a cart-load, of each variety of material taken from the pits should be placed upon a piece of firm level ground, and made up into conical shaped heaps. Three examples of each variety of material will be desirable; one made up into a heap without any addition to the moisture it possesses when excavated; a second with a little water added; and a third with a great deal of water added, that it may be in the condition of the puddle commonly used in England.

After these samples have had a few days to dry, you will be able to see which is most compact without cracking, and I request you will report the result.

I am going to look at the Pashan Dam this evening, and will send you any information that I may find worthy of note there.

To—*The Chief Engr. for Irrigation, Poona.* From—*Capt. C. B. F. Penny, R.E., Exec. Engr. for Irrigation.* No. 580 *of* 1868.

Dated Sholapur, 29th May, 1868.

Sir,—In accordance with instructions received in your letter No. 778 of the 16th instant, I have the honour to report as follows:—

Specimens of three kinds of material of which the *band* at Ekruk is being made were chosen, and three conical heaps were made of each kind. One heap was well rammed without any addition of moisture; a second had as much water added as is at present supplied to the *band*; and a third had a great deal of water added to it, reducing it to the condition of puddle commonly used in England. Of the three specimens of soil used, one was common black soil; another was a clay of a lighter colour with a mixture of kankar; and a third was a clay of a much lighter colour, with a mixture of kankar and other material, very like fine sand.

Of the black soil specimens, the heaps, without any addition of moisture, became a mass of dust on the outside, the inner part being a body of loose material. The heap, with a slight addition of water, was cracked all over on the outside, but the inner part appeared still to have moisture, and was firm. The heap, with a great deal of water added to it, was in deep cracks, and had nearly all crumbled away, leaving little moisture in the interior. It would appear in this last heap that in the process of drying, the large cracks formed had increased the evaporation, and that less moisture was left than in the heaps which had received only a slight addition of water.

The same results, only of a more favourable nature, were observed of the second kind of material used, viz., clay of a slightly lighter colour with an admixture of kankar. Of this material it was evident that a slight addition of water was of more benefit than a sufficiently large quantity to reduce it to puddle.

Of the third kind of clay used, that of a much lighter colour with an admixture of kankar and sandy material, there could be no doubt which heap was the most satisfactory. The one with no addition of moisture was a heap of fine dust with no adhesion of the particles; the heap with a slight addition of water was compact and moist in the interior, but the outer part was little dry and wanted adhesion; the third heap, however, with a good deal of water, was one compact mass, without scarcely a crack, and could be lifted up entire without breaking. When broken in half, the mass was found compact and moist.

C. B. F. P.

No. CCLXXVI.

BULL'S PATENT TRENCH KILN.

[*Vide* Plates I. and II.]

By W. Bull, Esq., A.I.C.E.

Further experience in the use of the Annular Flame Kilns, on which several Articles have been contributed to the Professional Papers from time to time, has led to very considerable modifications and improvements. The extent to which these improvements have been carried out will be shown by the following description, and its accompanying drawings.

The successful application of the Hoffmann system of top firing to the kilns as originally designed led to the discovery that with properly constructed chimneys and dampers, the admission of air for the combustion of the fuel by means of openings in the sides of the kiln could be entirely dispensed with. It at once became apparent that the kiln walls could be similarly dispensed with, or rather that the natural earth would answer just as well and keep in the heat much better. The result of the first trial far exceeded my most sanguine anticipations. The construction of the kiln is at once reduced to 16 per cent. of the cost according to the old plan. The absolute impossibility of any escape of heat or admission of cold air by the sides or bottom increases the economy of fuel, and greatly improves the draught and rapidity of burning, and the decreased cost permits of the new kiln, or process, being used for the smallest number of bricks down to a single lakh.

It may be of any width which can be conveniently fired. It may be a short straight piece worked periodically. It may be a long straight piece worked semi-continuously, or it may be circular, square, oval or oblong to work continuously. The process is the same in all, and in

different positions each may have its advantages. It will be very easy to adapt the instructions now given to any of the shapes mentioned.

The kiln is simply a chamber or excavation dug to the depth shown in the drawing with the bottom sides and top edges dressed off to a true surface. Of necessity not a single brick need be used in the construction. Doorways, flues, ashpits, openings of any sort and flooring are dispensed with.

When excavated and dressed off to the proper depth, the sides should be hand-plastered with a mixture of cow-dung and mud, as it causes the earth to hold together better.

The best form of kiln for regularity of out-turn is undoubtedly the circular one, but for a small number of bricks it would of course be most economical to construct a straight piece of a length in proportion to the number to be burnt. Except for the difference of distance from centre to centre of furnaces on the inner and outer faces of a circular kiln, the setting is precisely the same in both. In both cases that distance can be altered at pleasure, there being no fixed conditions of any kind between the kiln and the setting. What may suit one kind of clay may not suit another. When two or more kilns are required in the same brickfield, two straight pieces of one hundred feet each, joining two semicircles of the radius given in *Fig.* 1 will give a double kiln, not more than 300 feet being required to work continuously in the present plan. A ring of the mean length of 300 feet would not answer, on account of the great difference from centre to centre of furnaces in such a compending small circle.

For a long straggling brickfield, one long straight piece would probably be the most suitable. The whole being below the surface of the ground, or only slightly raised, the coolies loading and unloading can walk over along the kilns at pleasure.

In the drawings—

Fig. 1 is a complete plan of a kiln for working continuously on a small scale.

Fig. 2 is a part plan showing the method of commencing the setting, and the temporary wall for starting the firing.

Fig. 3 is a part plan showing the top of the setting, and the method of forming the feedholes.

Fig. 4 is a half plan of two complete chambers covered and ready for firing.

Figs. 5 and 6 give an exact longitudinal sectional elevation of one chimney length, and a portion of another. *Fig.* 6. shows the feedhole walls, and *Fig.* 5 the intermediate walls and chimney space.

Fig. 7 shows a half cross-section between feedholes.

Fig. 8 shows a half cross-section through feedholes and furnace.

Fig. 9 shows a templet for giving the position of the bottom brick between each furnace, and the width of the furnaces.

Figs. 10, 11, 12 and 13 show the details of the dampers to be used.

Figs. 14, 15 and 16 show the details of the chimneys.

Fig. 17 is a templet for giving the position of the bottom bricks in a circular kiln of the radius shown in *Fig.* 1.

In choosing a site for a kiln, a level piece of ground offers the greatest facilities, but is by no means a necessity as the sides may be partly raised by mud wall work or kucha brickwork. If the excavated earth is good for moulding purposes, it answers best to entirely excavate the kiln, if not I would recommend its being raised two feet, and the earth from the remaining depth utilized in levelling off a width parallel to the kiln, and the same height as the top on which to stack the wood. Two sets of steps which may be made of mango wood for the coolies to go up and down on are required. In all cases there should be slight fall away from the top edge of the kiln to prevent rain water running in.

A length of 50 feet or more having been excavated, and the bottom and sides treated as directed, loading can be commenced. The width of furnace is 13 inches, and the distance between 2 feet 9 inches. The near wall of the first furnace is only 1 foot 3 inches, and the far wall of the last in each length is 1 foot 6 inches. The latter has a greater tendency to settle down owing to the forward action of the flames. Each chimney length is exactly the same, and there should be six inches between each length to allow in the first plan of the dampers being dropped down; and secondly, as a smoke chamber over which to place the chimneys. The feedholes and chimney openings are shown in detail, and should be finished off with a pila brick at the top.

As each chamber is filled a compact layer of dry earth or ashes, *never less* than six inches in depth, should be evently spread over the whole, level with the top of the feedholes. In the cold weather some pila bricks may with advantage be set under the chimneys to catch the steam droppings. It is almost needless to say that the bricks should be as dry as possible.

It is not adviseable to pack the bricks very tight in the walls, but no actual space need be allowed, except in the three top bricks. Between the bricks of the 2nd and 3rd courses half-an-inch space should be allowed, and the top course should be composed of two bricks running longitudinally with three inches space between them. The spaces between the walls should never be more or less than three inches, and between the outer wall and the face of kiln four or five inches. If the bricks are longer than shown in the drawing the width of kiln must be proportionately increased.

Two chimney lengths and part of a third having been set, the temporary cross-wall with seven short furnaces at the foot of it, should be run up of loose bricks and smeared over with mud, the dampers should be put down the second chimney opening, and firing commenced in the cross-wall before mentioned, slowly to begin with. As steam ceases to rise out of each line of feedholes successively they should be closed, either with a couple of bricks or a thick square tile, of which a couple of thousand may be moulded specially for this purpose and burnt. Twenty-four hours after firing has commenced, the third chamber should be completely loaded, and the dampers withdrawn from the second opening, and put down the third. The chimneys should be put over the second opening, and the first closed up as well as all feedholes. This should be done as tightly as possible to allow of the full power of the chimneys being exerted. At the foot of the chimneys six or nine inches of dry earth or ashes should be spread to catch the condensed steam, which principally (but not entirely) runs out through the bottom joint, owing to the peculiar construction of chimneys.

When the heat in the kiln has got up to such an extent that the hand cannot be borne on the chimneys, they should be moved on as before. This rule for moving on the chimney should always hold good. By this time, if not before, the bricks forming the first furnaces will be red hot, and top firing should be commenced in the first row of feedholes. Three or four hours after a second may be commenced, and similarly a third. This is sufficient for regular working, but until the kiln has been once fired, it may be necessary to continue firing the feedholes next the wall after the three middle ones have been closed. Cast-iron caps should be provided to cover the mouths of the feedholes when burning, as anything of earthenware is sure to get broken.

The kiln will now be in full working, and the top and bottom firing

should be continued, until the first furnace has been sufficiently fired. This can be told by the settlement as well as by the appearance. The bottom firing should be slackened down then, but not discontinued until six furnaces are closed. It should then be stopped, and the furnace mouths loosely closed with bricks, but not plastered. Loading, firing, and moving on the chimneys should be going on in proper order, and when 15 furnaces have been closed, the mouths of the furnaces in the cross-wall should be plastered up, and air admitted by partly opening the first line of feedholes. The object of this is to prevent the smoke eddying back along the top of the passages. When 25 are closed, the first row may be opened entirely, and after that every fifth line, beginning with the 25th or 30th behind the firing. Between these and the dampers every feedhole should be carefully closed. The three rows firing only being uncovered when dropping in the wood or to see how the burning is getting on. The firing is very simple, and any smart coolie can be trained in a week. Just as much wood only as will burn freely without any accumulation of charcoal should be given, one piece generally to each hole about every half hour being sufficient. The system here detailed ensures such a regular distribution that the utmost perfection of burning is obtained. Except the bottom brick every individual brick below the brick flat should be thoroughly burnt, and with good clay and care, there need be no overburning. It is obvious that from being able to look down into any part at any time gives complete control over the working.

Any sort of tiles that can be set in the walls can be burnt, and with care, there need be no loss whatever, either from over or underburning. When forty or fifty furnaces have been closed, the part first fired will be ready to unload. The temporary wall may then be taken down. Four furnaces equal to 8,000 bricks may be burnt, the first time round and five the second time, when the kiln is thoroughly dried. The average consumption of fuel should not exceed 4,000 cubic feet of mango or 3,000 cubic feet of bābul, per lakh. For finishing off at the end of a season, a second temporary wall should be put up six inches from the end of a chamber, and the chimneys placed over the space so left. They must not be left then longer than the usual time for moving them, or they will be burnt. They should then be removed as usual, and a short chimney run up of bricks—four feet high is sufficient.

If a certain proportion of second class is required the loading may be

carried up two bricks higher, taking care to give little more space between the five top bricks. This is the maximum height that will burn well and economically.

In putting down the dampers, they simply have to be placed side by side, and the key or intermediate piece pushed down. The crack at the side should be smeared over with a little mud, and also along the top.

With regard to the apparatus used, the templets shown by *Figs.* 9 and 17 will be found most useful, as giving not only the position of the bottom course, but the width of the furnaces, by making a cut on the wall, opposite the forward edge, and then moving the hinder edge up to it. The chimney bench is six inches extra. The dampers should have a good coat of tar before use, but not the keys. If the latter get rusty and are stiff to move, a little oil rubbed on them will set it to rights. A set will last for years with care. Four middle and two outer sheets with five keys are required to form a complete damper for the kiln here shown.

The chimneys are shown of the utmost possible length which will permit of there being conveniently moved without being lowered, and if made as in the plan can be moved on a couple of stout bamboos with the greatest ease. In making them up a theoretically correct section has been sacrificed to simplicity of construction, and very little cutting is necessary. The four sheets to form the upper length having been riveted together, they can easily be bent over to make a big tube and riveted. The same with the second length. The short lower length is made by cutting one sheet into four pieces, and acting as with the others. In joining the lengths, the short lower one *must* always be inserted in the next one above it, and if the top edge can be bent in slightly so much the better. The object of this is to arrest all the condensed steam, and allow it to run out on to the layer of dry earth or ashes at the foot of the chimneys, instead of its dropping on to the green bricks and spoiling them. It may even be advisable to rivet a narrow strip inside the lower length of chimney to make sure of this. Two or more good coats of tar should be given to the chimneys, particularly inside and near the bottom. Without this the gases from the fuel, and the moisture together, will eat them away in a surprisingly short time. Before moving they should never be allowed to get too hot to bear the hand on for a moment, or they will be burnt. The distance will vary with the season, from 8 to 15 furnaces from the firing.

For the width of kiln shown in the drawing two are required. They should be protected against the action of the wind by stout bamboo struts. The cast-iron caps can be supplied by Messrs. Burn & Co. of Calcutta. They will be required for three lines of feedholes with two extra.

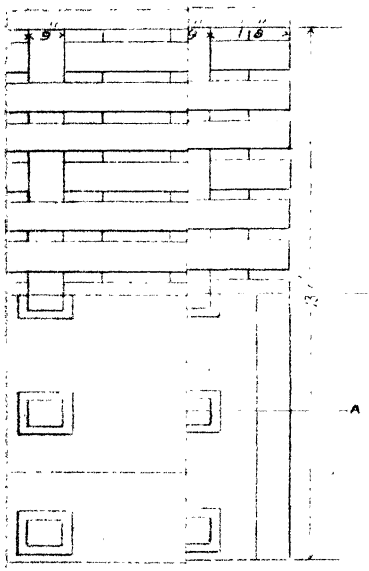
An estimate of the cost of a kiln similar to the one shown in the drawing is here given:—

	RS.	A.	P.
Earthwork 35,000 cubic feet, at Rs. 1-8, ...	52	8	0
Bricklayers dressing off bottom and sides, ...	24	0	0
Set of chimneys and dampers, ...	110	0	0
Caps (cast-iron), ...	30	0	0
2 sets of steps of mango wood, ...	6	0	0
1 templet, ...	5	0	0
Contingencies, ...	12	8	0
Total Rs., ..	240	0	0

It will be seen that the kiln itself costs only Rs. 75-8-0, or less than one-sixth of the cost of the most economically constructed kiln on the old plan. It is therefore, without exception, the cheapest kiln in existence, it is decidedly the simplest to construct, but even these advantages are subordinate to the fact, that owing to the method of working not a breath of cold air need ever touch a brick, which is likely to be damaged by it, thus ensuring a very high quality, as regards soundness and the maximum of economy, from the utilization of all waste heat.

I think it necessary to state, that the kiln itself, and the combination resulting from the adaptation of the Hoffmann system of top firing with wood to it, and other parts of my original invention, form the subject of separate patents.

W. B.



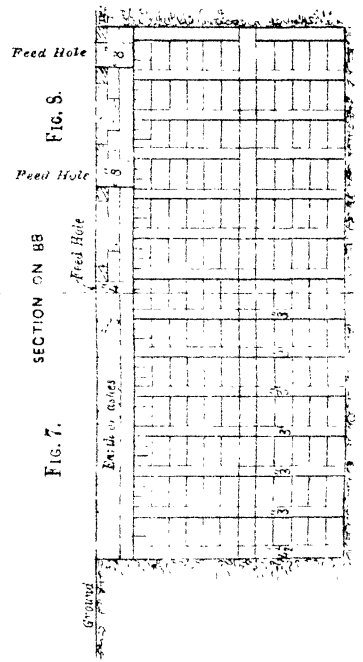
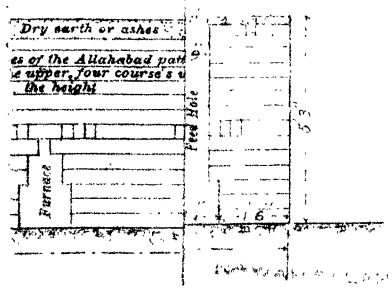


FIG. 8.

SECTION ON BB

FIG. 7.

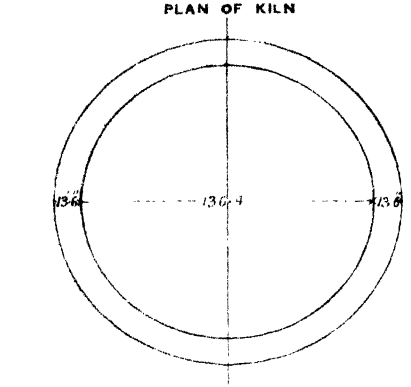
5.



BULL'S PATENT TRENCH KILN.

Scale. 4 feet = 1 inch.

Fig. 1.
PLAN OF KILN



Scale. 80 feet = 1 inch

CHIMNEY

Fig. 14.
Side View

Fig
End V

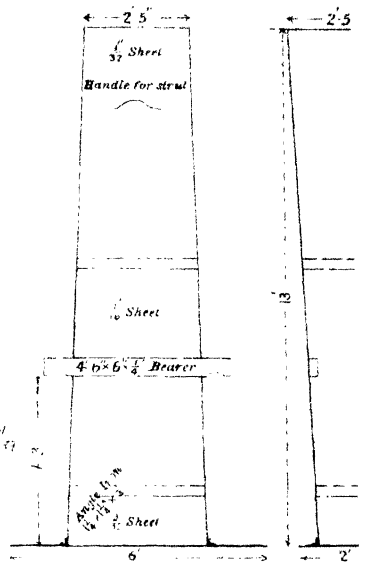
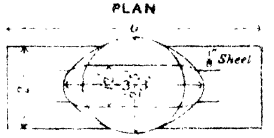


Fig. 16.
PLAN



DAMPER

Fig. 10.

½ Sized Section of guide at edge of Damper Sheets

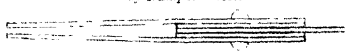


Fig. 11. *Middle Sheet*

Fig. 12. *Joint Piece*

Fig. 13. *Outer Sheet*

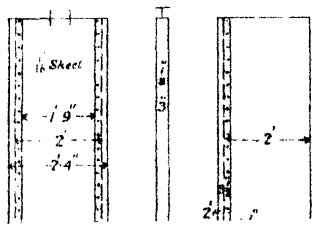


Fig. 9.
TEMPLET
For Setting bottom Brick in a rectangular kiln

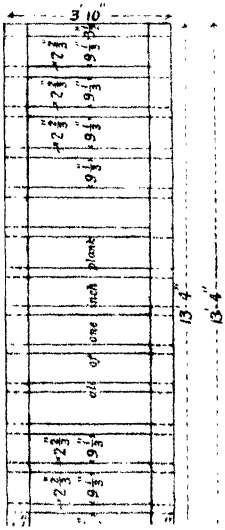
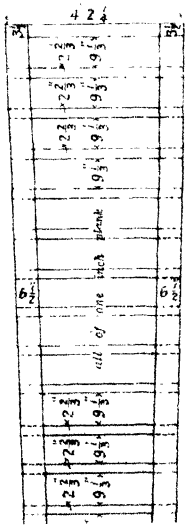


Fig. 17.
TEMPLET
for Setting bottom Brick in a circular kiln



No. CCLXXVII.

CHANNEL OF CONSTANT MEAN VELOCITY.

By Capt. Allan Cunningham, R.E., *Hony. Fel. of King's Coll., Lond.*

It is proposed to investigate the form of cross-section of a channel of given material, which shall have a constant "mean velocity", *for all depths* of flow, adopting the results of the latest published experimental research on the value of this quantity.

The real relation of this quantity to the various elements on which it depends is unknown: according to the theory proposed by Chézy, it appears that—

Mean velocity $\propto$

or in symbols $U = C \cdot \sqrt{rI}$, where C is constant,.....(2).

And with some hydraulicians, I is understood to mean—in a long uniform channel—the average slope* of the bed, which is therefore a *constant at any one place* in the same channel.

Adopting this Result (2), as a sort of first approximation and assigning the above meaning to I, it is clear that—in the same channel—the only variable in the expression for U is the hydraulic mean depth r; so that if U be constant, r must be constant: in other words.

"A channel of constant mean velocity for all depths at the same place, must be a channel of constant hydraulic mean depth". } ....(3).

The argument leading to the above Result (1) or (2) must be admitted to be very imperfect, amounting to no more than a plausibility of its truth. The course of experiment has indeed pointed out unmistakeably that the proposed relation is certainly *very far* from correct. However

* How far this assumption is legitimate is very doubtful: it seems probable that I should rather be taken as the "surface-slope", which is found—by experiment—not to be a constant quantity.

experiment has not yet established any laws of fluid of motion whereon to base any rational theory, so that no better formula has yet been proposed by theory. In the absence then of a rational formula, hydraulicians have been content to accept the above result, as a sort of *rough* first approximation and to write as above,

$$U = C \cdot \sqrt{rI} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4),$$

wherein however C is not a constant, but itself also a *variable* depending on many elements, the chief of which is perhaps the physical state of roughness (technically "rugosity") of the channel. The course of experiment of late years has been to investigate values of this coefficient C, and thence if possible the law of functional dependence. All recent experiment tends to show that this coefficient must be one which increases with increase of hydraulic mean depth.

The most important formulæ that have been recently proposed are—

1°.—BAZIN'S COEFFICIENT, $C = \dfrac{1}{\alpha + \left(\alpha + \frac{\beta}{r}\right)}$

wherein α, β are numerical quantities depending on the "rugosity" of the channel. This is based on the prolonged experiments of both Darcy and Bazin in 1855-60 in France on small artificial channels not exceeding 2 mètres in width or depth.

2°.—KUTTER'S COEFFICIENT, $C = \dfrac{m + 1 \div f}{\alpha + \frac{m}{\sqrt{r}} f}$, where $m = \beta + \dfrac{\gamma}{I}$

and α, β, γ are constant numerical coefficients, the same for all channels, and f is a quantity depending on the "rugosity" of the channel. This is based on a comparison of all experiments accessible up to the date of publication of the formula, (1870): and is therefore believed to be the best extant.

Now the quantities α, β in Bazin's coefficient, and f in Kutter's coefficient depending solely on the "rugosity" of the channel are clearly constant for the same channel at the same place.

And assigning the same meaning to I as before, (which makes it constant in the same channel at the same place), the only variable in both Bazin's and Kutter's coefficients is the hydraulic mean depth (r), so that in fine the only variable in the expression (4) for U is the hydraulic mean depth (r), and the same Result (3) is obtained as before, even with these new variable forms of the coefficient C, viz:—

"A channel of constant mean velocity for all depths at the same place, must be a channel of constant hydraulic mean depth".

It is easy to see that this remarkable result depends not at all on the functional *form* of the coefficient (C), but on its being a function only of

the rugosity, slope, and hydraulic mean depth : hence the above result will be equally true for any coefficient (C), involving only these elements.

The figure of the border of the cross-section of the channel, must possess the property of having a *constant hydraulic mean depth for all depths of flow*, i. e.

$$\frac{\text{Area of cross-section}}{\text{Wetted border}} = \text{constant}, \quad \ldots\ldots(5),$$

or expressed in the ordinary mathematical language,

$$\text{Area of curve} \propto \text{length of arc}, \quad \ldots\ldots(6),$$

coupled with the conditions that—

1°. The area and arc must be comprised between the same limits.

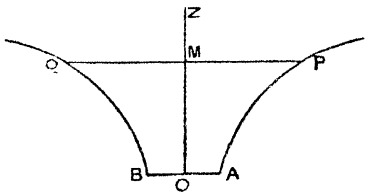
2°. The curve (of the wetted border), must be continuous between these limits.

Now it will be found that there is no curve which will satisfy *all* these conditions.

The condition (6) is a well known* property of the "common catenary,"

$$y = \frac{b}{2}\left(e^{\frac{x}{b}} + e^{-\frac{x}{b}}\right)$$

and it might be supposed that a pair of equal half-catenaries arranged as in figure with a common directrix OZ and vertices at A, B would satisfy



the conditions ; but their geometric property is, (writing $AO = b = OB$, $OM = z$, $PM = QM = y$).

Area $AOPM = b$. arc AP ; Area $OBQM = b$. arc BQ.

$\therefore$ Whole area $ABQP = b$. (arc AP + BQ).

whereas the condition that ought to be satisfied is—

Area $ABQP = b$. (arc AP + AB + BQ), $\ldots\ldots(6a)$.

The cross-section obtained is thus inexact to the extent of omitting the straight bottom portion AB, from the expression for the wetted border.

This mathematical solution moreover happens† to be *unique*, i. e., it shows that the catenary is the only curve possessing the property (6) ; it

* *See* Boole's Differential Equations Chap. XI., Ex. 2, Art 4.

† This would be recognized at once by any one solving the differential equation which expresses (6).

follows, therefore, that there is no curve possessing the required property (6*a*).

The solution though admitted inexact gives an *approximate* solution in two distinct ways.

Approximate solution 1°. If the bed-width AB be very small compared with the whole length PABQ of wetted border, or which is the same thing if the bed-width AB be small compared with the depth OM, the solution is approximate.

In this case $x \div b$ being a large quantity, the term $e^{-x \div b}$ is evanescent, and the curve approximates in form to the "logarithmic curve", $y = \frac{b}{2} e^{x \div b}$, so that the ordinates (y), or surface-width PQ increase very rapidly with increase of depth.

This figure is perhaps roughly approximated to in certain natural channels in sandy beds; the outline of a sand bank near the water surface often assuming the rounded form indicated by the curve above PQ.

Approximate solution 2°. Again suppose the bed-width AB to be not necessarily small, but consisting of a material opposing much less resistance to the current than the material of the banks: in this case also the solution will be approximate; and if the bed-width be also small compared with the depth, it will be highly approximate.

No example of this kind is likely to arise in either natural or ordinary artificial channels.

Approximate solution 3°. The above consideration suggests yet another approximate solution with a totally different section.

Suppose the section rectangular, and of great depth compared with its width, *i. e.*, of form shown in cut.



Here again the effective wetted border is approximately the same as the sum of the sides, (neglecting the bed-width): and the solution is approximate; and if the bed be of smooth, and the sides of a rough material, will be highly approximate.

This solution is not one likely to meet any illustration in ordinary practice, but it suggests immediately a means of testing directly by experiment, whether the expression for mean velocity $U = C . \sqrt{rI}$, ought really to involve only one variable element, viz., hydraulic mean depth besides elements depending on the rugosity, slope, &c., which are constant at the same place in the same channel.

Thus, if this law be true, then such a channel should be approximately one of constant mean velocity for all great depths, and the Discharges should therefore be approximately proportional to the depths. It is hardly possible to conceive a verification more simple in application, if the experiment itself be feasible. Unfortunately the experiment would certainly be very expensive if done on an adequate scale.

[*Previous investigations.* This question has already been investigated in Paper No. CLXI., Vol. IV., of these Professional Papers by Mr. F. E. Rose, who gave the figure of the pair of catenaries as the solution : the inexactness of this solution was pointed out in Paper No. CLXXIX., by Mr. E. Gramatzky ; the approximate forms of the solution were pointed out by the present writer in a "Note" at end of Mr. Gramatzky's Paper. But in all these previous attempts C was assumed constant. In the present Paper this unnecessary restriction is removed, and the values of C based on all the latest experimental data have been adopted].

A. C.

Giving different values to x (the gradient of the line) from 0 or dead level up to 1 in 4 in per thousands, we obtain the different train weights drawn by the locomotive. These are graphically represented on *Plate* IX., where the gradients are the abscissæ and the train weights the ordinates, the locomotive weights being below and the train weights above the horizontal axis A, A. *Plate* IX. also shows, for the sake of comparison, in a similar way the performances of a tender locomotive on the Engerth system as used on the Semmering, and those of a tender locomotive on the Uetliberg.

The Semmering Line has curves of 590 feet radius, and the trains on it travel at the rate of $10\frac{1}{2}$ miles an hour on a gradient of 1 in 40. Their locomotives have a total weight of 66 tons, of which $19\frac{1}{2}$ tons fall on the two axles of the tender; hence the adhesion weight is $46\frac{1}{2}$ tons. The drawing power of an ordinary locomotive is found by multiplying the adhesion weight into the coefficient of friction which is on an average $\frac{1}{7}$th, and in favourable circumstances $\frac{1}{5}$. The Semmering locomotive hence gives a drawing power of from $\frac{46{\cdot}5}{7} = 6{\cdot}65$ tons to $\frac{46{\cdot}5}{5} = 9{\cdot}3$ tons. As before,

$$G = \frac{6{\cdot}65 \text{ or } 9{\cdot}3}{\quad} = \frac{6650 \text{ or } 9300}{\quad}$$

Inserting the values x from 0 up to 1 in 4 in per thousands, we obtain the performances on these different gradients. These are shown on *Plate* IX. in yellow and brown lines.

Each of the Uetliberg locomotives, with 3 coupled axles, weigh 25 tons, all available for adhesion. Hence $\frac{25}{7} = 3{\cdot}57$ tons, and $\frac{25}{5} = 5$ tons. The train speed on curves of 590 feet radius is $12\frac{1}{2}$ miles.

$$\text{Hence } G = \frac{3{\cdot}57 \text{ or } 5{\cdot}00}{\quad} = \frac{3570 \text{ or } 5000}{\quad}$$

Substituting as before the different values of x, we obtain the blue and red curves in *Plate* IX.

Hence we observe from *Plate* IX. that on a gradient of 1 in 25 the Semmering locomotive (yellow line) is only just able to drag itself along, and on steeper grades it cannot even do that.

On *Plate* IX. by marking off the ordinates on the right hand vertical line, and from it towards the left hand marking the abscissæ on the

upper horizontal line the gradients increasing from right to left, we obtain curves showing the ratio of the weights drawn to the weights of the locomotive, the quotient of the former divided by the latter being shown by the coloured curves.

Some of the results of the readings of the curves from *Plate* IX. may be shown in the following Table:—

Weights	Cog-wheel Locomotive	Uetliberg Locomotive	Semmering Locomotive
Train tons exclusive of locomotive.	*Continuously.*	*Under favourable circumstances.*	
50	1 in 13	1 in 14	1 in 18
100	1 in 23	1 in 22	1 in 34½
200	1 in 50	1 in 40	1 in 91
300	1 in 83	1 in 70	1 in 250
Train weights in terms of the weights of the locomotive.			
Once its own weight, ..	1 in 6	1 in 16¼	1 in 11¼
Five times its own weight, ..	1 in 20½	1 in 80	1 in 50
Ten times its own weight, ..	1 in 42	1 in 340	1 in 143
Twenty times its own weight, ..	1 in 100	nowhere	nowhere
Thirty times its own weight, ..	1 in 250	nowhere	nowhere

A cog-wheel locomotive at Wasseralfingen on a metre gauge weighs 11 tons, and on a gradient of 1 in 12¾ draws a train weighing 28 tons, or 2¾ times its own weight; whereas an Uetliberg locomotive weighing 25 tons on 1 in 14¼ can only draw a train of its own weight.

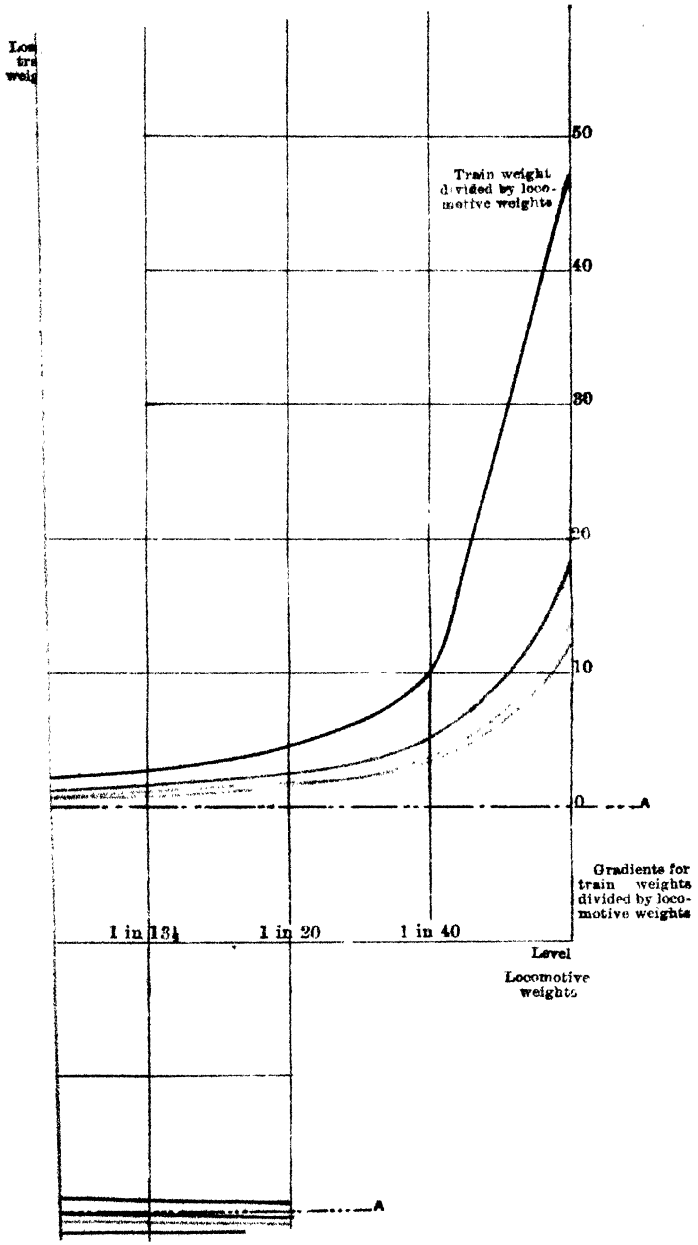
WEAR OF TEETH AND DURATION OF RACK-RAIL.—The results obtained from fourteen cog-wheel locomotives show that in a locomotive giving a tooth pressure of 6 tons, the average wear on the teeth is—

·00000003761 of an inch at every touch.

The wheel-circumference is 10½ feet and the maximum allowable wear ·2358 of an inch, which wear will be reached after the locomotive has run

$$\frac{\cdot 2358 \text{ in.} \times}{} \text{ feet}$$

$$= 12450 \text{ miles.}$$


Train weight divided by locomotive weights
50
40
30
20
10
0
A
Gradients for train weights divided by locomotive weights
1 in 13½
1 in 20
1 in 40
Level
Locomotive weights
A

No. CCLXXVIII.

EARTHWORK ESTIMATES.

By Major A. M. Brandreth, R.E., *Offg. Principal, Thomason C. E. College, Roorkee.*

My only excuse for entering the following Memo. on Earthwork, which was written as a text-book for the College Students, in the "Professional Papers" is, that the second place of decimals is a kind of red rag to me, and I would fain hope that any one who uses it, will read my arguments and become convinced, and save himself and others under and over him much labour by omitting it. With regard to the Prismoidal formula I may say the same, only I do not believe that is extensively used. My Top Lift suggestion, para. 32, is such an obvious improvement that I cannot believe it is mine; and finally, I wish to ask consideration for Students who join the Department as young hands when found using these *apparently* rough methods as they have been taught. The Slope Table (Sheet IV.) is a handy thing, and can be had at College Book Depôt, Price 0-2-0. The colours are only intended to keep the eye to the right column belonging to the particular estimate in hand; and so with many apologies, and no desire to teach those who have thought the matter out, I venture to start my proposals.

Memo. on Estimates for Earthwork.

1. The elaborate form for earthwork (*see* Sheet VI.) given in our Estimating Manual, and also the treatment of the subject in the Roorkee Treatise, Vol. I., Section II., Chapter VIII., are not the practical ways of working out Estimates. Part of the following is included in my previous Note on the Estimating Course, but I had not then time to work this subject out fully. Even "on the works" much unnecessary labour is gone through in Earthwork Surveys and Estimates, because men have got into a groove and do not think whether or no it is the easiest one to run in. Earthwork varies so in circumstances that affect its shape that explanations to embrace even the typical varieties must be somewhat

lengthy, but I hope the following will be found simple and easy if taken, as intended, step by step.

2. The general principles are the same as for any other estimates, the estimate should be practically accurate, and should show all the detail that can ever be required, and it should be done in the simplest form, so that if possible all the work may be done by a clerk or other uninstructed estimator. I have never found any difficulty in getting complete detailed estimates made into my forms from the plan sections, or indeed field-book, by the office baboo.

3. By practically accurate, I mean accurate enough for all practical purposes, *i. e.*, measurement and payment for work done. It should be remembered to start with—firstly, that earthwork is measured by the *thousand* cubic feet, and that the rate per thousand is a small sum, Rs. 1-8 to Rs. 3 say, and therefore a difference of a few hundred feet, or even thousand feet, in a large estimate, is not of great importance; secondly, in all estimates however close the measurements are taken, in the estimate it *must* always eventually be considered that the lines and planes joining the points measured on the surface of the ground are straight, while it is evident (see *Fig.* 1, Sheet I.) that the natural surface must go in curves. (*Fig.* 1 is a real extract from the survey this year picked out by chance, the curve is of course only drawn as near as I could imagine the natural one to be,) therefore here there must always be an unavoidable difference from the actual quantities; and thirdly, that the measurements in laying out and measuring up the work must differ from the actuals considerably, and therefore all these three heads show it is waste of labour to attempt to estimate with minute accuracy, if it does really involve any labour, about which I can assure you, from painful experience, there is no manner of doubt whatever. It should also be remembered that you have to satisfy contractors and workmen with your measurements, and they prefer simple ones that they can understand, but of course it is always well to get as near the real thing as we can without going to unreasonable trouble. The chance of arithmetical error and the necessity of arithmetical check are also strong arguments in favour of very simple estimates.

4. First then to take earthwork estimates in the Plains where the cross slope is not taken into account. All that the survey gives, or need give, is the centre line of levels at even distances. It will be seen afterwards what trouble is given by having the readings at all sorts of intervals, and

it is very seldom worth while to attend to the figure of the ground along the centre line in this way, readings at even distances give quite accurate enough results. If there is a sudden rise or fall which really must be noticed the readings to its corners should be made intermediate ones at the correct distances, but the next forward staff should go all the same to the even distance, so as to keep the complete distance to any peg always that number of station times the even distance, *i. e.*, where l is the even distance, station n is nl from starting point. The importance of this is evident when it is remembered that the R. L. of the canal bed or road surface as the case may be has to be estimated at each station by the slope from the first, and this is a great worry and moreover difficult to check when the distances vary.

5. The difference then between the R. L. of the natural and artificial surface, either cutting or bank is taken out for each peg or station down the centre line at even distances from 100 feet for very detailed estimates, to 500 or 1,000 feet for rough preliminary ones, and the first question that arises is, what should that distance be ? For a final estimate for road or canal it should generally be 100 feet as the work is given out to contractors, and paid for, in 100 feet lengths in most cases, but for trial or preliminary estimates a vast deal of labour may be saved in all ordinary country by using as long distances as the level will read to. To show this, I mention, that I took an estimate for a large canal over 100 feet bottom and 40 miles long worked out to 100 feet distances, and with readings to two places of decimals, and made a rough one of the same using the readings at 1,000 feet apart taken to the nearest half foot. The difference between the two was 1·6 per cent. No doubt 1·6 per cent. is a good deal on a large quantity, but the question is, is any detailed estimate within 1·6 per cent. of the final payments, or again within 1·6 per cent. of the actual quantity, both which may be very safely answered in the negative. Any one can test this for himself by treating any detailed estimate as above. The saving in labour in the field and office is great, and therefore it should be noted that great attempt at accuracy by frequent readings is waste of time except for final estimates.

6. The next point is the accuracy required in the readings, and here I would put in a word of warning to young levellers, that mistakes do not occur in the reading of the hundredths but in the feet and tenths. I see beginners read off 5·6 or 4·2, or whatever it may be at a glance, carelessly

in fact, and then spend minutes screwing their eyes to read the 100th division to a half of itself, while all the time the error is a foot or a tenth. The golden rules are to work at even distance each side of your level for back and fore shots, to use the legs to level the instrument and the foot screws as tangent screws only, and to take care of the feet and tenths first. However this is aside, the question is the accuracy necessary in estimates. We *must* have the second place of decimals in the field-book, for bench-marks, and also for the back and fore sights, as the error of only using one place though small may accumulate, but we may at once decide never even to *read* an intermediate shot closer than the nearest tenth. And here nothing is saved to your eyes if you *will*, as I have seen, read to the second place and then enter to nearest first—read boldly to nearest tenth at once—if the wire is so near the middle that you cannot decide at once whether to read up or down, be sure it does not matter which you do.

7. In making up the book the intermediate shots may be called 3·40, 7·30, &c., and the R. L. worked out as usual to two places, which is perhaps the simplest way (*see* Centre Example, Sheet II.); but whatever method is used, the R. Ls. when taken *out* of the book on to the plan or elsewhere, should *always* invariably be *only* taken to the *nearest tenth*. The field-book may be, if it is desired to have the R. Ls. only to tenths at once, made up thus (*see* Third Example, Sheet II.)—Add back and fore sights and find difference, 0·56, add this to 5·51 the R. L. at top of page making 6·07, which is of course the last R. L. in the page and ready *to carry over to next page*, and correct to second place so that no error can *accumulate*. Then treat all your readings as of one place only, and take out rises and falls to one place, and make up R. Ls. all down page to one place only, using 5·5 to start from. It is a mere trick gained in a day's practice to use 5·07 as 5·1, and 1·67 as 1·7, &c., *vide* Example of the Three Plans.

8. The middle plan is perhaps the best, as the errors in a page may accumulate to about 0·2 by the last method. This cannot carry on of course, but certain pegs may be recorded 0·2 higher or lower than they are. I only note the plan as suitable for trial levels. It will of course be observed that any error even in *reading* an intermediate staff does not in any way affect the accuracy of any but that one point—and a caution may be given, that fore and back and intermediate shots should be in three separate columns always, as the convenience of working is evident.

9. The only points then entered on a plan with two places of decimals will be the B. Ms., and in estimates the second place will *never* appear. The saving to the eyes in the field, and in entries in the field-book and on plans, both in labour and clearness is evident at a glance, and is really a valuable quantity on both heads—the question is, is *anything* lost by it? *All* we lose is the accuracy in the R. L. of the actual points on which the staff was put, *i. e.*, we may enter any point 0·1 higher or lower above the sea level than it really is. In the first place, the point is not a reality, as the staff is put on a peg and the cooly with the head of his *phăorā* driving it treats the 100ths rather inconsiderately; and in the second place that exact level can never be found again when you come to lay the work down; while lastly, you never measure the work or even give the contractor orders to dig or bank to nearer than the 10ths. Yet it is a fact that to this day hundreds of estimates are yearly worked out to two places, and plans smothered in extra rows of figures. I hope then the Roorkee Students will insert the small end of the wedge by getting into the habit of confining their second places to their field-books entirely, and to the back and fore sights and B. Ms. in these.

10. In taking out the bed or surface slope, say the R. L. at starting station is say 7·2 and the slope is 1 in 5000. Then for 100 feet lengths the drop is ·02, but we do not use this, we take ·1 off every fifth 100, as below—we cannot dig closer than this, try ever so hard, so why calculate. In case the slope is not an even one like this, but say 1 in 3700, I always work out a 1 foot to the correct decimal and then change them into the nearest one place, and use that order of intervals at which to subtract 0·1 all along thus:—

1 in 5000.				1 in 3700.									
0		·0	7·2	0	·000	·0	7·2						
1		·0	7·2	1	·027	·0	7·2	16	·432	·0	6·8	31	·837	·0	6·4
2		·0	7·2	2	·054	·0	7·2	17	·459	·0	6·8	32	·864	·0	6·4
3		·0	7·2	3	·081	·0	7·2	18	·486	·0	6·8	33	·891	·9	6·3
4		·0	7·2	4	·108	·1	7·1	19	·513	·5	6·7	34	·918	·0	6·3
5		·1	7·1	5	·135	·0	7·1	20	·540	·0	6·7	35	·945	·0	6·3
6		·0	7·1	6	·162	·0	7·1	21	·567	0	6·7	36	·972	·0	6·3
7		·0	7·1	7	·189	·2	7·0	22	·594	·6	6·6	37	·999	1·0	6·2
8		·0	7·1	8	·216	·0	7·0	23	·621	·0	6·6				
9		·0	7·1	9	·243	·0	7·0	24	·648	·0	6·6				
10		·2	7·0	10	·270	·0	7·0	25	·675	·0	6·6	Level spaces of 400			
11		·0	7·0	11	·297	·3	6·9	26	·702	·7	6·5	or 300 feet, then drop			
12		·0	7·0	12	·324	·0	6·9	27	·729	·0	6·5	off 0·1 in fixed order			
13	Drop 0·1 every 500 feet.	·0	7·0	13	·351	·0	6·9	28	·756	·0	6·5	of occurrence in each			
14		·0	7·0	14	·378	·0	6·8	29	·783	·0	6·5	3700.			
15		·3	6·9	15	·405	·4	6·8	30	·810	·8	6·4				

11. One other delusion should be swept away, that is the number of readings required in the cross sections of line at each station. I have known a canal 200 feet bottom, for which a breadth of 350 feet was crossed by sections, every 50 feet with readings at 50 feet intervals on each, and the mean of these 7 readings was taken as the reading at each 50 feet; I doubt if there is much ground in the Plains where this labour would repay one. If the ground was level but uneven the mean might give a nearer result; but if, as is more likely, there was a cross slope, in the first place the centre reading was probably the mean of the seven, so the labour was wasted, and in the second place it would not give a correct result as I shall show when I speak about estimates in really sloping ground presently.

12. Here was an instance of the idea that a number of figures must mean accuracy. The principle I wish to get you to realise is, be accurate by all means but do not fancy that a *number of figures* always means an *accurate result*; or again that the accuracy gained by the number of figures is in amount worth the labour and extra chance of error involved.

13. For the present, remember we have got to the fact that we have from our plan or field-book the height of bank or depth of cutting D measured to tenths at each station, and that the stations are l apart, which l is always an even hundred feet at all events.

14. The content of the earthwork between any two stations, *i. e.*, for length l is the whole estimate, as this repeated makes up the whole line.

15. The usual practical way of obtaining the content is to take the mean of the two depths, *i. e.*, $\frac{D + D'}{2}$, say d, and finding the cross section at this depth multiply it by l. Thus content $= l\,(Bd + sd^2)$ where Bd is the central part and sd^2 the two side slope triangles (*see Fig.* II., Sheet I.)

16. This is *quite* correct for the centre portion, *i. e.*, as far as the Bd or larger part is concerned, but of course for the sides the correct quantity would be given by the Prismoidal formula

$$\frac{ls}{6}\left\{D^2 + D'^2 + 4\left(\frac{D + D'}{2}\right)^2\right\} \text{ or } \frac{ls}{3}\left(D^2 + D'^2 + DD'\right).$$

Instead of this the simpler form $ls\left(\frac{D + D'}{2}\right)^2$ is used, and the difference is therefore—less quantity— $\frac{ls}{12}(D - D')^2$. Some men still use the Prismoidal formula, and it is given in our College Example of Estimating, and on our principles if this is a material difference the more complicated

formula should be used, but we are equally bound to see first whether it is worth the extra labour and chance of error in calculation. Let l be 100 feet, $s = 1{\cdot}5$. Now if D − D′ is 0·5 feet then $\frac{ls}{12}(D - D')^2 = 3$ cubic feet, and 3 feet per 100 feet length of canal or road is say 150 feet a mile, a quantity at ordinary earthwork rates of Rs. 2 or 3 per 1000 feet, certainly not worth any labour at all. The difference assumed, 0·5, is a very fair average for 100 feet lengths, but the quantity varies as square of difference, so if D − D′ was even 2 feet, which is absurd as an average, the quantity per mile would only be 16 times 150 feet, or 2,400 feet, which is really of no consequence in a mile, while the extra labour of using the Prismoidal formula is enormous.

17. It will not run into any form while the simpler formula so easily does (*vide* Sheet III., Form I.) The estimate comes out in shape $Bd + sd^2$, and *therefore* we make the Form with columns to fit. The actual depths D, D′, &c., are entered off the plan to left opposite the number of station, (and here note that this and each succeeding step can be done by any clerk,) the means of each pair of D and D′ or the values of d are run out into next column, then column Bd for centre filled in, and *when that is done for a page* column sd^2 for side slopes is filled in, and *then* the two are added for whole area into next column and *then* multiplied by l into final column of content; of course if l is 100, one of these columns can be dispensed with. Now not an unnecessary figure has been put down and every figure is recorded. A second man can check the work without using another sheet of paper even. This is a great point to note in all calculations, that no scraps of paper should be used and thrown away, only do the necessary figures and have a regular place for all so that all work done is recorded for check, it saves labour both first and last. I have gone into detail over this simple thing because it contains the principle of the whole, *i. e.*, work out your estimate into an algebraic shape that can be done in easy steps, and fit your forms to that shape.

18. Naturally the question arises, but are there not earthwork tables which will give the area of the section or the content for all values of d. The reply is—there can be no complete ones. B varies for each case and s also varies, and therefore the number of tables for a complete section would have to be infinite. We can however as s has not many usual values, have tables for sd^2, for $s = 1$, $s = 1{\cdot}5$, $s = 2$, $s = 2{\cdot}5$, $s = 3$, &c., and for any

long estimate the easiest way is to make a table of values of Bd for all expected values of d and then fill in column Bd from that. The easiest way to do that is to enter the values of d as in Table II. (*see* Sheet III.) between the expected limits, and having worked out the value Bd for the first entry, write 0·1 times B on the lower edge of a slip of paper, place it *above* the first entry add for the second, move the slip down one line to over the second and add for third, &c., checking at every foot. I mention this little plan merely as an example, now there is a better way of doing everything. Try the difference of any other plan, even adding the same put on the top edge of a bit of paper. Having got Table II., values of Bd, and also Table I., values of sd^2, it will strike you, if you have a long estimate that your best way instead of filling in Form I. for the whole estimate will be to make a table in that form for all your expected values of d once, and then in your long estimate you can use a new form, or the same, omitting columns Bd and sd^2, and area, and fill in total content, at once; but here you want Form I. to make the table of contents for each value of d, *i. e.*, you will find using Form. I. the easiest way you can do it.

19. Now sd^2 tables would be so useful generally that I have decided to print them, and have worked out a set for 0·1 to 20·0 for five slopes, *i. e.*, 0·5, 1, 1·5, 2 and 3 to 1, correct to two places decimals, but on filling in Form I. as a specimen as shown in upper half herewith, it is evident that about one quarter the labour of addition was caused by the last two figures, and I therefore tried what difference it would make to omit them, *i. e.*, make the tables to the nearest whole number. The result is given in lower half of sheet. The difference is 50 cubic feet in 500 feet length of canal, a quite immaterial quantity, and the saving of labour by estimating in whole hundred feet in this way is evident. This is only a short example, but it will be seen that the greatest error possible in any one length is where 0·5 is made 1·0, *i. e.*, 100 or l times this, and therefore the amount of error we have in five stations may occur in one. In the first station the error is 38 feet, in first two it is 32, in first three it is 18, in first four it is 36 again. Sometimes in excess sometimes the other way, but very unlikely to accumulate all one way, and therefore on no grounds does it seem worth taking in these two figures. Therefore the tables I have made out (Sheet IV., Table I.) are for 100 cubic feet, and it only requires a little struggle to give up these fancied accuracies. Now there has not been a step hitherto that any clerk could not do, and though much more extended

forms are necessary for more complicated sections of work, the parts of each are just as simple, it is only the number of columns that is extended.

20. I give another example (Sheet V.), a portion of the Lucknow and Fyzabad road, which forms Example 19 of our Estimating Manual, as I wish to contrast the labour and the results in the plan of estimate there adopted and the one I recommend. First notice that at station 33 there are two readings, *i. e.*, a sudden drop at the station, and the means are of course that of the reading at 32 and 0·5, and that of 5·7 and the reading at 34. Next, in cases as at station 40 and 41, where d is positive at one end of a length l and negative at the other, *i. e.*, if the bed cuts ground surface between two stations, (*see* dotted Example, *Fig.* 1. Sheet I.) The only thing needed is to make two lengths of the one 100 with a reading of 0·0 at the junction and use the correct length of each. It can be done in smaller figures in the same line so as to keep the same even number of stations in each page, as should be arranged for all large estimates, half a mile, or so many thousand feet in each page. The following method is often useful:—

If p is the positive reading and n the negative, then the length of the part of l nearest p will be $\frac{p\,l}{(p+n)}$ and the other piece $\frac{n\,l}{p+n}$, or in case 40 and 41, $\frac{35}{35+17}$ and $\frac{17}{35+17}$, about 70 and 30 feet. In Example 19, 50 feet has been taken for each, and I have adhered to this to allow of comparison of my estimate with the other.

21. The great difference is in stations 38 and 39 and in the last four stations which, in Example 19, are lumped, *i. e.*, 32,874 and 22,996 against 33,300 and 24,300 as given by my method, but if these stations are worked out separate in the same way and form as the rest of the estimate, (*see* Sheet VI., Form Y.,) it will be seen that the correct results are 33,258 and 24,268, so I am actually nearer than the example. The labour of estimating in the two forms will not bear comparison. To begin on Form Y. it is necessary to work out a Table of Sections, and this cannot be done in an easier way than by doing my whole estimate, and yet after this there is all the labour shown in Form Y. all for nothing at all, to produce exactly the same result, to all real intents and purposes.

22. Note that though two places of decimals were used in all the entries and means of depths at considerable labour the next moment

they had to be abandoned, as the Table of Sections is only made to tenths. In hundredths it would have been quite too voluminous. Note also that centre column of areas is not plain extract from the Table it is four times the extract—and last column is one-sixth of the total of three previous columns. I have shown this for one line in Form Y., if not recorded it would all have to be done again if the estimate has to be checked. Note too the extra labour caused by the decimals in the Table, *i. e.*, compare the work done in stations 56 to 60 in Form Y., and in my estimate, even supposing the Table for that particular section was ready to hand, which is absurd. It is all absurd—not real—and though you may think that in stations 56 to 60 there is not much difference after all, wait till you have worked out a long estimate.

23. To return to our forms let us take a more difficult section than the first, say a canal with a fixed bottom width B, side slopes s to 1, and banks of breadth together equal T at top and height h above the bed, to be made whenever the depth of the excavation is less then h. This h is fixed of course a certain height, 2 or 3 feet say above the full supply level. Here we may have all cutting or all bank or some of both, (*vide Figs.* 3, 4 and 5, Sheet I.,) and there may be too much earth excavated which has to be disposed in *spoil banks*, or there may be too little for the banks so that the extra quantity has to be obtained from *side tanks*, and as these spoil banks and side tanks have to be arranged for, the estimate must give us all detail in quantity, not merely the total quantity of earthwork. It must do this if it is a detailed or final estimate. If it is only an approximate estimate, and we only want the total quantity, the plan is in each length to calculate *either* the excavated channel or the made banks according to which is *greater*. Thus, if for any sized canal we find by a few trials the depth of excavation which just gives enough earth for the banks, and call this depth e, then whenever the depth is greater than e, we calculate the excavation only, and wherever it is less than e, we calculate the made banks only.

24. For a section of this detail the general Algebraic form to include all these cases, is

Excavated channel, ... $Bd + sd^2$ as before,

Banks, ... $T(h - d) + 2s(h - d)^2$.

The second expression for the banks is merely two of the other, as it were. The sections are exactly the same only upside down, and of height

or depth $(h - d)$. The form then will be as Form II., Sheet VII., to accommodate the above expression, and to fill in is just as simple as Form I., only takes a little longer. I have omitted the column for multiplying by l given in Form I. in this and Form III., as l is always 100 and so the column is not needed. It can be added of course if another length is used.

25. An example of ten stations is given showing all the cases that can occur. The first three columns as before give us the values of d. The next step is to fill in column H, or $h - d$, omitting entries when d is greater than h or $h - d$ is negative, in this case there will evidently be no bank so no calculations are made. Similarly, when d is negative there should be no calculations of channel as then there is evidently no actual excavated channel. It is necessary to enter the negative values of d to obtain $h - d$, which in this, *i. e.*, the third case is the sum of h and d.

26. Columns L and M, Spoil and Tank, are evidently the difference of column D and K according to which is greater, while column M, Total Excavation, is the entry in either column D or K according to which is greater.

27. Each column can be filled in by any clerk, and Tables made for them in just the same way as before. Always noting to work one column at a time, down the paper not across, *i. e.*, all entries of one sort at once, then another sort, and so on. Each step is necessary, each can be checked. In this form it will be observed that the filling between banks when bed is above ground is not provided for, *i. e.*, the triangle ELMF, or as it would usually be a trapezoid, (*see Fig.* 5, Sheet I.) Up to the limiting case here shown where d is as large as $\frac{B}{2s}$, a quite impossible case, the area would simply be $Bd - sd^2$, and might be entered if desired in small figures, or with a negative sign to distinguish it from channel *excavation*, in columns B and C, Form II., and the difference taken into K. There would be no other entries in P and C, as d is negative in this case.

28. If we are making a rough estimate using e we fill in either channel *or* banks, and take on into total leaving other columns blank. In this example, $e = 3{\cdot}4$, so in the first 8 entries excavation only would be calculated and in the last three the banks only.

29. To go one step farther and take a more complicated case of section, subtituting *Fig.* 6 for *Fig.* 3, or arranging to dig out tow-paths or roads of width R at the fixed height h when d exceeds h. Then Form III., Sheet

VIII., which is only an increase of a column or two on Form II. gives everything. The detail about top and bottom lift is a new item to be explained presently. Here the expressions for the three cases possible for the section as in the figures are—

Centre channel, ... $Bd + sd^2$

Tow-paths, ... $R(d - h)$

Banks, ... $T(h - d) + 2s(h - d)^2$

and the form as before is only so many separate columns. If the same rule as before is followed, *i. e.*, make no calculations in that particular column when d, or $d - h$, or $h - d$ in the heading is negative, all will come out right. It is just as before for centre and banks, and if in tow-paths $(d - h)$ is negative there are none as d is less than h, *i. e.*, it is either *Fig.* 2 or 3. The columns A to K are filled in as before one at a time, then spoil is column D and F less column K, or rather it is D + F *or* D − K, as there can be no entry in F and K in the same line, *i. e.*, in the same 100 feet length of canal. If K is greater than D this is the excavation from tanks necessary to complete banks and goes in column M; and lastly, the total is given in N, by D + F + M, or rather D + F or D + M, as F + M do not occur in the same line.

30. The same remarks apply as before—there is no labour wasted. Every figure put down here would have to be put down, and any clerk can do each line in succession; if he is very slow, explain one at a time and let him do it first, and then ask how he shall fill in the next column. If less detail is needed columns may be omitted as shown in case of Form II. We can work with e here also.

31. Any other form of section would be arranged in the same way, the Form would be arranged to suit the algebraic expression for the section. For a long estimate this should be done in the form of a table for all likely depths by tenths in order, first, and then the actual estimate filled in to a form with one column for d and another for content or such details of content as are wanted, from this table.

32. Lastly, there are the columns at the end of Form III., called Top and Bottom Lift, which I believe to be a novelty and well worth introduction for working estimates and payments. Work is always or often done and paid for roughly in lifts, of a certain depth, thus 16·5 deep excavation would perhaps be in five lifts of 3 feet each, and an odd one of 1·5 feet. My idea is to have the odd lift first and then the regular 3 feet ones to the bottom.

The result of the change on the usual reverse practice of having even lifts from the top and the odd one to finish up with is, that the lifts, numbered from the bottom, are the same content and work, everywhere as long as the bottom width is the same, instead of varying with the depth of excavation. Thus if the bottom width is 112 feet, side slopes 1·5 to 1, the first lift is $112 \times 3 + 1{\cdot}5 \times 3^2 = 350$ feet, and each lift above this is 2×3^2 or 18 feet additional. If the depth is 11·3 there is first one of 2·3 feet then three, *i. e.*, Nos. 3, 2 and 1. If it is 16·7 there is first one of 1·7, then Nos. 5, 4, 3, 2, 1—same numbers have same content all down the line. The saving in check measurements and avoidance of confusion would be really very great. The sums to be paid for each lift would be household words and no reference to books, &c., would be needed. As a rule, the first odd lift would be kept in hand, not paid for till the end, so that the payments would be just for the lift according to its number, and there would be but a few different sums to pay, as ten lifts means deep digging. The final payment would be for the whole section less what had been paid for lifts. If it is desired to pay the first lift it is only the difference between the total section and so many lifts, which could very soon be run out for miles of line. The printed forms for some Canals contain columns for this, but they are a business to fill in as they begin the even depth from the top. I have put similar columns in Form III. Column O is just the number of lifts, *i. e.*, the times 3, or whatever the lift depth is, goes into *d*. Column P is content of this number of lifts, filled in from a scrap of a table containing content 1st lift, content 1st two lifts, 1st three, &c., and column Q is just the difference between this and column D, when there is no entry in F, and column N when there is any. The Table of Lifts will include the tow-path. But as I said before, I should not put these in, but keep the top lift in hand and pay only the regular even lifts.

33. In Hill Road making, and possibly in some other cases, it is necessary to take the cross slope into account. Let us first consider the cross slope as a straight line (*see Fig.* 7, Sheet I.) The data given by the survey at each peg on the centre line of the road would be the height or depth of road surface from the peg, or CH, and the cross slope of the ground, either by two levels or by angle. We want to find out the area of cutting and bank at the station and also the measurements to the points CB and CB′, on the sloping ground. The only satisfactory way to do this is to draw a

good diagram and measure on it, calculation is very laborious and a mistake as the data even are not really exactly accurate, and therefore the measurements from diagram are just as likely to be right as calculations. But for a long road with many sections a number of diagrams is a considerable labour and a very cumbrous record, and I should therefore adopt a plan as shown in Sheet VIII., *Figs.* 1 and 2 and Form IV.

34. The section of road with indefinite slopes is drawn out in *Fig.* 1, and scales marked on it, those on the slopes are the vertical heights and depth carried across, but double the scale so as to read half the real height. *Fig.* 2, which must be drawn on tracing cloth, is the ground surface. The centre dot is adjusted over the correct cutting or bank on the centre line, (*Fig.* 1,) and to the correct slope also by the angle lines for the purpose, or by another reading of height above road at the half width adjusted by the scale at this point, and all dimensions needed, and also the base and half verticals of the triangles of cutting and bank can be read off into Form IV. at once. This needs no explanation, except that the arrangement here is, that if there is more than the breadth of road in either cutting or bank it is taken out level to hill side—*see* figures in corner of Sheet VIII. of Extreme Sections. Form IV. makes a convenient record of the work, and in this the detail of any length of road could be carried in the pocket.

35. For the Estimate Form IV. gives the areas of the sections. Now, let a and a' be the areas at the ends of a length l and m, the section at the middle point—not the real section, but supposing a and a' connected by straight lines—then for the content of the prismoid we may either take roughly $l \cdot \frac{a+a'}{2}$, or correctly $l \cdot \frac{a+4m+a'}{6}$. The difference is $l \cdot \frac{a+a'-2m}{3}$, and as it seems that this may be an appreciable amount, I have drawn out Form IV. to work the correct formula. Thus the entries of d and cross slope at the numbered stations are the actual Field-book measurements, and give a and a', and the unnumbered lines contain the entries for means which will give m. The working is plain from the example given. In the first length $a + a'$ is $156 + 126 = 282$, and $2m$ is $2 \times 142 = 284$, so that the error in using $\frac{a+a'}{2}$ would be $100 \times \frac{2}{3}$, or 70 cubic feet. In the next station, it will be $40 \times \frac{13}{3}$ and $60 \times \frac{8}{3}$, with different signs, or about 13 cubic feet; in the third, it is 2,300, an appreciable quantity as

this is an extreme case. But the above shows that the differences may be considerable, and therefore the Prismoidal should be used. It may be observed the areas at the actually measured stations may be entered in the "detail" column at once. There is no need to enter them twice.

36. In Hill Roads, or indeed any section where the ground surface cannot be taken as a straight line, quite another arrangement is necessary, but here the utmost detail of measurement that could be justified, would be readings on each cross section line at even horizontal distances from the centre, to both sides (*see* Sheet IX.) The extra accuracy of each section gained by readings to the special angular point on each cross section at uneven distances, such as P, P in figure, would be quite swallowed by the inaccuracy of the necessary supposition that these corners of any two adjacent sections are joined by straight lines. For the same reasons, it would be entire waste to use the Prismoidal in a case like this, and all that can be hoped for in this case is a fair average result, and the point is to arrange that the calculation shall be possible.

37. I never had to estimate to this exactness, but if I had I should adopt some such form as No. 5, Sheet IX., commencing with my Field-book. It appears as simple a one as will record and work out all the information required. I have given two stations, both plotted, and arranged Form V., Sheet IX., underneath, and worked out to decimals to show process, not that in practice I should enter them. The top line of the set of three at each station is the R. Ls. or readings at the section at the even distances *b*, say 5 feet. *N.B.*—I should make it quarter or some even fraction of the road width. The second line is the same for the road surface, to right the rise for slope is added and to left the fall deducted. In this latter case, *i. e.*, to left, if the road is in cutting at B, no deduction for slope is made, it is carried out level as in second example. Similarly if road is in bank at A no *addition* is made for slope. The third line then gives the Bank and Cutting at each peg on the cross section The change of sign shows where the road and ground surface cut, the second change, as in first line showing where the slope again cuts.

38. To work out estimate of areas of the cutting there are two little triangles and a centre figure. The triangles are as before $\frac{p}{2} \times \frac{p^2 h}{p+n}$, the centre is $b \times$ sum of $\frac{1}{2}$ first and last, and all the intermediate ones of the positive quantities. These are entered, omitting the common factor b,

and multiplied by it after being added together at one operation. If b came an uneven quantity, say $\frac{1}{4}$ of a 17 feet road, a table of multiples of 4·25 would pay. The estimate is mean of areas multiplied by l. This is all step by step work on plain rules, can be done line by line as before. The distances to right and left horizontally measured are so many spaces as there are positive quantities to either side of centre $+ b \frac{p}{p+n}$.

39. Exactly the same process carried out to left hand would give the bank.

40. In the case of a Large Canal or Road in the plains, I do not myself believe that the cross slope would often be worth taking notice of, but I have seen a case of a large canal, as I mentioned before, where the order was for cross sections at every 50 feet to 150 feet each side of centre line, with readings at every 50 feet on them. The mean of the seven readings on each cross section was taken as the mean R. L. of the section, and for each 100 feet length of canal excavation d was the fourth of the sum of the extreme means and twice the centre mean. Now this was a very great deal of labour, the question is, was it well expended, *i.e.*, was the accuracy gained in result worth it? If the ground was generally level but uneven it would give a more correct result than chancing the centre readings to be average. I should in this case even doubt whether it was worth the labour.

41. But if, as is more generally the case, the unevenness is by way of a cross slope, the mean reading is very near the calculated mean—and also what is more important, the mean will not give a correct result at all, but, taking an extreme figure to show it plainly, it will be wrong by triangle ADB (*see Fig.* 8, Sheet I.) If then the slope is worth regarding at all it must be regarded in another way, *i. e.*, one that will at all events tend to an accurate result. I am not sure that the form of book, Sheet IX., given for hill roads would not be as simple as most in a case of real irregularity. We save all the labour of taking the means of the readings, and I doubt is the total work greater than any other form. Of course the left side would go up as the right only does in this case, in fact the section, &c., would be of canal not road. But if the ground is really sloping, perhaps a way of finding the value of triangle ADB in each case might be simplest. The calculation would then be made for the mean depth, *i. e.*, AA′H = ADB′H), and ADB added. As the cal-

culation will only be for the small portions, ADB, they need not attempt any great accuracy. It may be well also to have a way of deciding how far the slope affects a case. The arrangement for this may be shown in Sheet X. and Form VI.

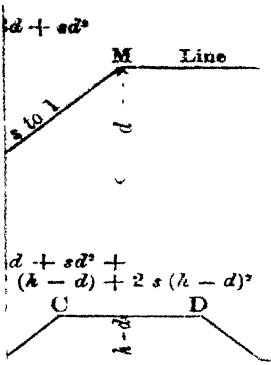
42. The point E, *Fig.* 2, then represents the same as E in *Fig.* 1. It is only necessary to construct a figure similar to *Fig.* 1 for each section required (*i. e.*, each value of *d*) round E on *Fig.* 2, and record the dimensions. *Fig.* 4, a stiff straight scale is adjusted with its zero at the correct half breadth, *i. e.*, EC on EA′ and at the given slope, either by the protractor at its left end or by the difference in level at the half width on EF. It then represents the ground surface. *Fig.* 3, which is really ADB, or rather the two sides of it indefinitely prolonged, is slid along line EA′, *Fig.* 2, till the scale on its bottom edge makes EA to right of E equal to the depth of the excavation. This scale is made *s* times the real scale, as EA is equal $s \times$ CH. The area of the triangle cut off by *Fig.* 4, the ground line, is then read, base on right and half height on left side. As in this case the cross slope would not vary often, it would not be a very troublesome job. If it did even it would be no worse than making sections. *All* entries required, including the widths at which the cutting commences, on each side, are made in Form VI. If the section of the canal was as given in Form III., it would only be necessary to add the width of the tow-path to the half width set off with the scale on EA′, when *d* read over the height fixed for the tow-path or *h*. Working with this, it will be seen that where the cross slope was 5°, depth 10 feet, bottom width 200, the mean reading gave an error of about 100 feet in section, or 10,000 cubic feet per 100 feet length. This is a difference of 7 feet about in the half width which is of course rather an extreme case. A difference of level of 1 foot in the half width of 100 makes about 20 feet difference in section, or 2,000 feet in the content of the 100 feet. An instrument of this kind, which any one can make for himself to a good large scale on a sheet of paper, and using a Holtzapffel's card scale, will at all events tell him whether the slopes of ground he has to deal with are worth noticing, and when they are so will give him the areas quite accurately enough.

43. I will just enter the practical method of finding the side widths on the ground given in the Treatise. It is applicable to any case, no matter

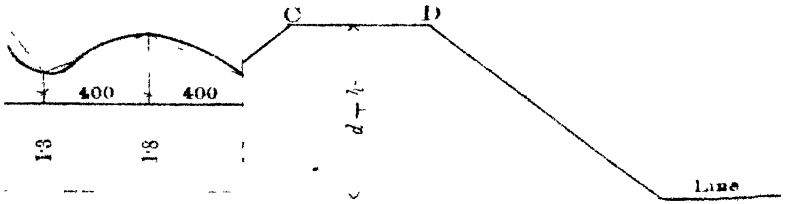
how irregular the cross slope. The principle is that $BN = \frac{AN}{s}$ for *any* point in the side slope (*see Fig.* 9, Sheet I.) We have only then to find a point *on the ground* fulfilling the above condition and we know it must be in the side slope also. If then we mark *a* the horizontal position of A on the ground distant $\frac{B}{2} + sd$, from C, and measure from it any trial horizontal distance $AX = x$ to a point Y, and then take the difference of level between C and $Y = y$; if y happens to come equal to $\frac{x}{s}$ we know we must be on the point B. If y is greater than $\frac{x}{s}$ we see we must be above the cross slope and therefore must increase our trial x, and *vice versâ* if y is less than $\frac{x}{s}$ we must decrease. Similarly if we are at the down slope, only in this case x must be measured inwards from a'. The only practical difficulty is the measurement of CA and AX horizontally.

44. In conclusion, you will observe that Earthwork is not so simple, *i. e.*, cannot be arranged for in one form, but that each case should be arranged for. I sincerely trust no one will think I advocate any careless or inaccurate work, but let us work with our eyes open. Let us utterly avoid the second place of decimals except where we know it is necessary, and let us avoid laborious estimates which give no better results than very much shorter and simpler forms.

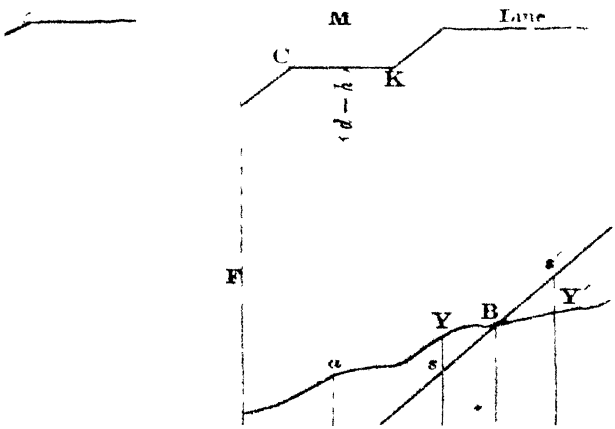
A. M. B.



$+ d)^2 - \left(\begin{matrix}\text{Fig. EFML}\\ Bd - sd^2\end{matrix}\right)$



, two Tow-paths
d.



OF WORKING LEVEL FIELD-BOOK.

Back.	Inter.	Fore.	Rise.	Fall.	R. L.	No.	Back.	Inter.	Fore.	Rise.	Fall.	R. L.
07	...	...	...	...	5·51	1	...	...	...	...	...	5·51
..	3·40	...	1·67	...	7·18		...	...	...	1·7	...	7·2
..	7·30	...	...	3·90	3·28		...	...	...	...	3·9	3·3
..	3·30	...	4·00	...	7·28		...	...	...	4·0	...	7·3
..	4·90	...	...	1·60	5·68		...	...	...	...	1·6	5·7
00	...	2·08	2·82	...	8·50	2	...	...	...	2·8	...	8·5
..	4·80	...	...	0·80	7·70		...	...	...	...	0·8	7·7
10	...	7·52	...	2·72	4·98	3	...	...	...	...	2·7	5·0
..	4·80	...	...	2·70	2·28		...	...	...	...	2·7	2·3
38	...	4·10	0·70	...	2·96	4	...	...	...	0·7	...	3·0
..	5·00	...	...	1·62	1·36		...	...	...	...	1·6	1·4
19	...	4·54	0·46	...	1·82	5	...	...	...	0·5	...	1·9
..	4·80	...	...	0·61	1·21		...	...	...	...	0·6	1·3
68	...	3·67	1·13	...	2·34	6	...	...	...	1·1	...	2·4
..	4·80	...	...	0·12	2·22		...	...	...	...	0·1	2·3
29	...	3·56	1·24	...	3·46	7	...	...	...	1·2	...	3·5
..	4·70	...	...	0·41	3·05		...	...	...	...	0·4	3·1
44	...	3·90	0·80	...	3·85	8	...	...	...	0·8	...	3·9
..	4·70	...	...	0·26	3·59		...	...	...	...	0·3	3·6
30	...	5·42	...	0·72	2·87	9	...	...	...	...	0·7	2·9
..	4·70	...	...	1·40	1·47		...	...	...	...	1·4	1·5
94	...	4·20	0·50	...	1·97	10	...	...	...	0·5	...	2·0
..	4·80	...	3·14	...	5·11		...	...	...	3·1	...	5·1
77	...	5·30	...	0·50	4·61	11	...	...	...	...	0·5	4·6
..	4·80	...	...	1·03	3·58		.	...	...	...	1·0	3·6

Form I.

	Area of centre portion B d.	Area of side slope $s\,d^2$.	Total area.	Distance between stations.	Content.	Remarks.
						B = 112. s = 1·5.
5	840·00	84·38	924·38	100	92438	
4	828·80	82·14	910·94	,,	91094	
0	784·00	73·50	857·50	,,	85750	
6	739·20	65·34	804·54	,,	80454	
3	705·60	59·54	765·14	,,	76514	
					426250	
5	840	84	924	100	924	In this case, decimals omitted, result in 100 feet—total difference 50 feet.
4	829	82	911	,,	911	
0	784	74	858	,,	858	
6	739	65	804	,,	804	
3	706	60	766	,,	766	
					4263	

Table II.

d.	B d.	d.	B d.	&c.
	11	2		B = 112 feet.
	22	4		*Method*.—Enter d for one Column, fill in top B d putting decimal to right in next Column, as shown in columns 5 and 6 (wrong place). Add 11·2 in succession.
	33	6		All above in pencil, correct in ink to nearest whole figure and rub out decimals and proceed with next Column.
	44	8		Make clearly different figures in columns d and B d and have even number of tens in Column
	56	0		
	&c.	&c.		

EXAMPLE IN FORM I. B = 30. $s = 2$.

n.	Mean of D or d.	Centre Bd.	Slopes $s\,d^2$.	Length l.	CONTENT. Cutting.	CONTENT. Bank.	Quantities given by Example 59. Cutting.	Quantities given by Example 59. Tons
7	...	...	...	100	...	...	...	...
0	− 2·9	87	17	„	104	...	10263	...
4	− 4·2	126	35	„	161	...	16136	...
5	...	...	...	„	...	...	...	...
7	− 2·5	75	13	„	88	...	8804	...
5	5·1	153	52	„	...	205	...	20485
6	4·1	123	34	„	...	157	...	15698
9	4·3	129	37	„	...	166	...	16636
1	5·2	156	54	„	...	210	...	21016
2	4·8	144	46	„	...	190	...	32874
3	3·8	114	29	„	...	143		
5	3·4	102	23	„	...	125	...	12518
7	1·8	54	6	50	...	30	...	3003
7	− 0·9	27	2	50	15	...	1371	...
2	− 2·0	60	8	100	68	...	6615	...
7	− 3·0	90	18	„	108	...	10767	...
0	− 2·9	87	17	„	104	...	10223	...
7	− 1·9	57	7	„	64	...	6147	...
0	− 0·9	27	2	100	29	...	2661	...
0	2·0	60	8	85	...	58	...	5834
	4·2	126	35	100	...	161	...	16094
	3·1	93	19	„	...	112	...	11343
	1·4	42	4	„	...	46	...	4630
	0·6	18	1	50	...	6	...	519
	− 1·1	33	2	70	25	...	2410	...
	− 2·4	72	12	100	84	...	8358	...
	− 1·5	45	5	„	50	...	5072	...
	− 1·5	45	5	„	50	...	4885	...
	− 1·8	54	6	„	60	...	6090	...
	− 0·5	15	0	50	8	...	783	...
	0·8	24	1	50	...	13	...	1145
	1·5	45	5	„	...	50		
	1·6	48	5	„	...	53	...	22996
	1·9	57	7	„	...	64		
	2·2	66	10	„	...	76		
					1018	1865	100525	184708
ns 37 and 38 and 56 to 60 from ... ... Total,					...	...	...	55870
					..	...	...	128838
ntities, Form Y, Total,					...	...	...	57466

Form Y.

Form as given in Example 19.

Area of Sections.			Mean of Cols. 1 & 3	Dist.	Contents.		Remarks
S_1	$4S_2$	S_3	Column.		Cubic.	Acres.	
220·32	615·12	120·78	164·07	200	...	32·814	As lumped in Example
220·32	76·32	161·28	130·32	100	,,	13032	Correctly in same Form
161·28	571·52	120·78	113·26	,,	,,	11326	
						57072	Total
						57000	Total as per short estim
49·50	219·80	75·68	37·43	100	...	22000	As lumped in Example
49·50	198·00	49·50	49·50	100	...	4950	
49·50	212·48	56·12	52·62	,,	...	5262	Correctly in same Form
56·12	256·88	75·68	64·28	,,	...	6428	
75·68	302·72	75·68	75·68	,,	,,	7568	
						24208	Total
						24300	Total as per short Estim

Work in top line.
161·28
4
645 12

Form II.

12, $s = 1{\cdot}5$, $h = 10$, T = 40, then E comes = 3·4

L. (Bd + sd^2) × l Content	Mean height of bank $\frac{h+d}{2}$	BANKS. T $(h-d)$ or centre of banks Table III.	$2s(h-d)^2$ or slope of bank Table I.	T $(h-d)$ + $2s(h-d)^2$ × l Content	Spoil.	Tank.	To exc tan
D	**G**	**H**	**I**	**K**	**L**	**M**	**J**
1157	0·8	32	2	34	1123	...	
1282	...	...	...	...	1282	...	
1565	...	...	...	..	1565	...	
1688	...	...	...	...	1688	...	
1385	...	...	...	...	1385	...	
1033	1·7	68	9	77	956	...	
726	4·0	160	48	208	518	...	
406	3·8	152	43	195	301	...	
124	8·2	328	202	318	...	194	
...	11·2	448	376	330	...	330	
...	11·9	476	425	901	...	901	

Form III.

ion l.	Excavation tow-path.		Content of banks				Content of spoil	Content of tank.	Total excava-tion	Dein top an tom	
D	**E**	**F**	**G**	**H**	**I**	**K**	**L**	**M**	**N**	**O**	**I**
B+C	$d-h$	**E×B**	$h-a$	**T** $(h-d)$	$2s(h-d)^2$	**H+I**	**D+F−K**	**K − D**	**D+F+M**		

T = width of bank

No. CCLXXIX.

ON EXPERIMENTS WITH SLEEPERS AT HOWRAH ON THE EAST INDIAN RAILWAY.

[*Vide* Plate.]

By Capt. H. Wilberforce Clarke, R.E., *Offg. Dty. Consulting Engineer to the Government of India.*

In October 1877, it was proposed to submit certain forms of sleepers to competitive trial.

At Howrah a siding 2,000 feet in length was thrown up on which the experiments were carried out.

The east end of the siding was at mile 1, and the west end at a point 400 feet beyond the Distant Signal of Howrah Station. The whole was on a curve, the radius of which was 5,200 feet.

The line was laid on formation-level, and so far completed on 6th November 1877.

2. Beginning from the $\frac{\text{station}}{\text{east}}$ end of the siding, the following sleepers were laid in lengths of 50 feet for trial:—

a. Greaves' iron bowls, 1′ 10½″ in diameter.
b. Denham's flat iron-plate-sleepers with flat tie-bar.
c. Olpherts' flat iron-plate-sleepers with round tie-bar.
d. Norway-pine-creosoted sleepers, 10′ × 10″ × 5″.

From their position, the Denham and Olpherts' sleepers were subjected to a more severe test than the other two kinds of sleepers, as the speed of the engine which traversed the siding was greater in the centre than at the two extremities.

3. The following Table shows the weight of one cast-iron bowl-sleeper of the Greaves' pattern (*Fig.* 1):—

No.	Details.	Weight in lbs.
2	Cast iron Greaves' bowl-sleepers, ...	172·0
1	Tie-bar, ...	35·9
4	Gibs and cotters (2 of each), ...	3·11
2	Keys,*	2·58
	Total weight of one bowl-sleeper complete, ...	213·59

The following Table shows the cost of one mile of way:—

No.	Details.	Rate.		Amount.		
		Rs.	Unit.	Rs.	A	P.
460	Rails, 10,560 feet,...	$1\frac{3}{16}$	foot	12,540	0	0
1,840	Sleepers, Greaves' bowl (complete),	8–3–2	each	15,084	2	8
920	Fish-plates, ...	$\frac{1}{16}$	,,	575	0	0
1,840	Bolts and nuts, ...	$12\frac{1}{2}$	100	230	0	0
129,030	Cubic feet of ballast, as for timber-sleepers, ...	4		5,161	0	0
	Total cost of one mile of way laid with Greaves' bowl-sleepers, ...			33,590	5	8

4. *Fig.* 2 shows the nature of Denham's cast-iron sleepers.

* The wooden key is 8" long.
$2\frac{3}{4}$" × 2" at one end,
$2\frac{3}{4}$" × $2\frac{1}{16}$" at the other end.
The mean sectional area is 5·585 in
The content is 44·68 cubic inches.

The following Table shows the weight of one Denham sleeper complete:—

No.	Details.	Weight in lbs.
	Bearing plates, Denham's pattern,* ...	163·55
1	Tie-bar, ...	12·5
2	Keys, ...	2·58
2	Chairs, ...	49·0
2	Gibs and cotters, ...	2·5
4	Bolts and nuts, ...	4·87
	Total weight of one Denham sleeper complete, ...	

Messrs. Thomson and Browning claim for the Denham sleeper the following advantages:—

(1.) That, in the case of lines already laid with sleepers and chairs, it takes the place of the sleeper only; the chairs laid in the road can be used.

(2.) That, in its use, there is more than ordinary freedom from liablity to fracture.

(3.) That, in its use, there is greater elasticity than ordinary.

(4.) That it can be adapted to curves, by increasing the gauge by reversing the positions of the cotters and gibs. When the gibs are inside, the sleeper is correctly laid for a straight line.

(5.) That it is suitable to all kinds of ballast.

(6.) That it is easy to pack; that a small quantity of ballast is required on account of its shallow depth; and that the saving in the quantity of ballast would cover the extra first cost of the sleeper.

Messrs. Thomson and Browning, further state that these sleepers have been tried on the East Indian Railway during a period of seven years, on other broad-gauge lines, and on the Indian (State) Railways.

* This weight was obtained by actual weighing. By the plan, the weight of two bearing plates (Denham's pattern) is 137·5 lbs. only.

3. The following Table shows the weight of one cast-iron bowl-sleeper of the Greaves' pattern (*Fig.* 1):—

No.	Details.	Weight in lbs.
2	Cast-iron Greaves' bowl-sleepers, ...	172·0
1	Tie-bar, ...	35·9
4	Gibs and cotters (2 of each), ...	3·11
2	Keys,*	2·58
	Total weight of one bowl-sleeper complete, ...	213·59

The following Table shows the cost of one mile of way:—

No.	Details.	Rate.		Amount.		
		Rs.	Unit.	Rs.	A.	P.
460	Rails, 10,560 feet,...	$1\frac{3}{16}$	foot	12,540	0	0
1,840	Sleepers, Greaves' bowl (complete),	8–3–2	each	15,084	2	8
920	Fish-plates, ...	$\frac{10}{16}$	„	575	0	0
1,840	Bolts and nuts, ...	$12\frac{1}{2}$	100	230	0	0
129,030	Cubic feet of ballast, as for timber-sleepers, ...	4	...	5,161	0	0
	Total cost of one mile of way laid with Greaves' bowl-sleepers, ...			33,590	5	8

4. *Fig.* 2 shows the nature of Denham's cast-iron sleepers.

* The wooden key is 8″ long.
$2\frac{1}{2}$″ × 2″ at one end,
$2\frac{1}{2}$″ × $2\frac{1}{16}$″ at the other end.
The mean sectional area is 5·585 inches.
The content is 44·68 cubic inches.

The following Table shows the weight of one Denham sleeper complete:—

No.	Details.	Weight in lbs.
2	Bearing plates, Denham's pattern,*	163·55
1	Tie-bar, ...	12·5
2	Keys, ...	2·58
2	Chairs, ...	49·0
2	Gibs and cotters, ...	2·5
4	Bolts and nuts, ...	4·87
	Total weight of one Denham sleeper complete, ...	235·0

Messrs. Thomson and Browning claim for the Denham sleeper the following advantages:—

(1.) That, in the case of lines already laid with sleepers and chairs, it takes the place of the sleeper only; the chairs laid in the road can be used.

(2.) That, in its use, there is more than ordinary freedom from liablity to fracture.

(3.) That, in its use, there is greater elasticity than ordinary.

(4.) That it can be adapted to curves, by increasing the gauge by reversing the positions of the cotters and gibs. When the gibs are inside, the sleeper is correctly laid for a straight line.

(5.) That it is suitable to all kinds of ballast.

(6.) That it is easy to pack; that a small quantity of ballast is required on account of its shallow depth; and that the saving in the quantity of ballast would cover the extra first cost of the sleeper.

Thomson and Browning, further state that these sleepers have tried on the East Indian Railway during a period of seven years, other broad-gauge lines, and on the Indian (State) Railways.

* This weight was obtained by actual weighing. By the plan, the weight of two bearing (Denham's pattern) is 137·5 lbs. only.

In the following Table the cost of one mile of way laid with the Denham sleeper is given:—

No.	Details.	Rate. Rs.	Unit.	Amount. Rs.	A.	P.
460	Rails, 10,560 feet, ...	$1\frac{8}{16}$	foot	12,540	0	0
1,840	Sleepers, including all bolts, &c., but excluding chairs, ...	8	each	14,720	0	0
920	Fish-plates, ...	$\frac{10}{16}$	„	575	0	0
1,820	Fish-plate bolts and nuts, ...	$12\frac{1}{2}$	100	230	0	0
129,030	Cubic feet of ballast as for timber sleepers, ...	4	...	5,161	3	0
3,680	Chairs, ...	$\frac{12}{16}$	each	2,760	0	0
	Total cost of one mile of way laid with Denham sleepers, ...			35,986	3	0

5. *Fig.* 3 shows the nature of Olpherts' iron-sleeper.

Mr. Olpherts claims for his sleeper the following advantages:—

(1.) That it is simple, and that its parts and fittings are few.
(2.) That it is suitable to all kinds of ballast.
(3.) That by it, accuracy in adjustment and in keeping to the gauge can be maintained.
(4.) That the use of an elastic cushion of seasoned sāl wood, under the rail, is most advantageous.
(5.) That, in its use, there is economy in first cost and subsequent maintenance.
(6.) That it can be adapted for use as a joint-sleeper.

Mr. Olpherts describes his form of sleeper as follows:—

The plate is of cast-iron, oblong in shape, with a bearing surface of 400 to 500 square inches, according as the sleepers are of a light or heavy pattern. On its *upper* surface there are two ribs in the direction of its length; on its lower surface, three ribs at right angles to its length.

Between the upper ribs, cast as a part of the plate and ribs, is a half-chair, similar to the ordinary chair, but rather heavier at the base. This is the *fixed* jaw of the chair-sleeper, and may be placed on the inner or outer side of the rail. The opposite half of the chair is *moveable*.

In the centre of the plate, between the upper ribs and two jaws of the chair, is a cushion of seasoned sāl wood, intended to save wear and tear of the bottom

table of the rail, to absorb vibration, and to lessen the effects of shocks to the rolling stock.

The moveable jaw, the wooden cushion and rail are secured in place by a wrought-iron tie-rod, which also preserves the gauge and inner inclination of the chair.

The following Table gives details of the weight and cost of the different parts of the Olpherts' sleeper:—

Parts of the Sleeper.	No.	Weight. ct. qrs. lbs.	Rate. Rs.	Rate. Units.	Amount. Rs. A. P.	Remarks.
Sleeper, cast-iron pair, at 100 lbs. each plate, ...	1	1 3 4	77 1/8	ton	6 15 1	Rs. A. P.
Tie-bar, wrought-iron, ...	1	0 0 21	20 1/8	cwt.	3 13 10½	One joint chair sleeper complete, ... 12 1 5½
Chair-bolts 15' long, ...	2	0 0 6½	8	,,	0 7 5	,, ordinary sleeper with ties (complete), ... 10 15 11½
Wooden cushions, ...	2	0 0 2	3/32	each.	0 3 0	,, ,, without ties, ... 7 3 6
						Tie-bars are supposed to be placed alternately; those sleepers which have not a tie-bar are supplied with two *chair-bolts*.

Credit by less cost—

	Rs.	Rs. A. P.
2 ordinary chairs at ...	1/8 each	1 8 0
4 spikes, ...	3/16 ,,	0 4 0
2 keys, ...	35 per hundred	0 1 2
		1 13 2

The following Table gives explicitly the weight of the Olpherts' sleeper complete:—

No.	Details.	Weight in lbs.
2	Bearing plates, Olpherts' pattern (chairs inclusive), ...	202·0
1	Tie-bar, including nuts, ...	21·0
2	Cushion of wood, ...	2·0
	Total weight of one Olpherts' sleeper complete, ...	285·0

The following Table shows the cost of one mile of way laid with Olpherts' sleepers:—

No.	Details.	Rate. Rs.	Unit.	Amount. Rs.	A.	P.	Remarks
460	Rails, 10,560 feet, ...	$1\frac{3}{16}$	foot	12,540	0	0	The rates are those of the Workshops of the East Indian Railway at Jamalpur.
260	Pairs of C. I. joint chairs and sleepers, ...	$12\frac{17}{1792}$	pair	3,143	0	4	
660	„ ordinary sleeper with ties, ...	$10\frac{333}{864}$	„	7,258	4	6	
960	„ „ „ without ties, ...	$7\frac{19}{32}$	„	7,290	0	0	
920	Fish-plates, ...	$\frac{19}{32}$	each	575	0	0	
1,840	Fish-pate bolts and nuts, ...	12	100	230	0	0	
96,722	Cubic feet of ballast, ...	4	100	3,870	14	0	
	Total for one mile of line laid with Olpherts' sleepers, weight per mile 308 tons,* ...			34,907	2	10	

Mr. Olpherts considers that the weight of each plate of the sleeper should be 100 lbs., and that the difference in price between his sleeper and a first-class sāl sleeper with fittings would be Rs. $1\frac{1}{2}$, or Rs. 2, more for the iron-sleepers.

In his letter of 12th December 1877, he states that—

(1.) A pair of sleepers was placed in January 1877 on the road leading off the main road to the engine-shed at Dinapur on the East Indian Railway; and that 7,348 engines passed over it.

(2.) Sixteen pairs of sleepers were placed in March 1877, at mile 342 in the up-main line, East Indian Railway, on brick-ballast, on the leved; that all trains passed at full-speed; and that 3,135 engines passed over them.

(3.) Ten pairs of sleepers were placed, in April 1877, at mile 178 on the down-line, on quartz ballast, on a descending gradient of 1 in 200, on the East Indian Railway; that all trains passed at 40 to 50 miles per hour; and that 2,684 engines passed over them.

Each of the platee of these three sets of sleepers weighed 90 lbs. only.

The Agent, East Indian Railway, in his letter No. 185 of 14th December 1877, to the Board of Directors, states:—"Cast-iron sleepers of the

* The additional cost of:—

a. A tie-bar to each Olpherts' sleeper

Nos.	Rs. A. P.	Rs. A. P.	Rs. A. P.
= 960	(3 10 10 − 0 7 5)	= 960 ×	3 3 5½
= Rs. 3,270 3 0			

b. The full section of ballast

$$= \frac{4}{100}(1,29,080 - 96,722) = \frac{4 \times 32308}{100} = 1,292 \text{ Rs.}$$

Hence the total cost per mile of way laid with Olpherts' sleepers

= (34,907 + 3,270 + 1,292 Rs.

= 39,469 Rs.

Denham and of the Olpherts' patterns have been in use on a small scale on the open line with satisfactory results."

6. The Norway-pine-creosoted sleepers require no description. The following Table gives the weight of one timber sleeper complete :—

No.	Details.	Weight in lbs.
1	Timber sleeper, ...	117·0
2	Keys, ...	2·58
3	Chairs, ...	49·0
4	Chair bolts, ...	4·875
	Total weight of one timber sleeper complete, ...	173·45

In the following Table, the cost of one mile of way laid with timber sleepers is given :—

No.	Details.	Rate.		Amount.		
		RS.	Unit.	RS.	A.	P.
460	Rails, 10,560 feet, ...	$1\frac{3}{16}$	foot.	12,540	0	0
1,840	Sleepers, ...	5	each	9,200	0	0
3,680	Middle chairs, ...	$\frac{12}{16}$	,,	2,760	0	0
3,680	Keys, ...	35	1,000	128	12	9
920	Fish-plates, ...	$\frac{10}{16}$	each	575	0	0
1,840	Fish-plate bolts and nuts,...	$12\frac{1}{2}$	100	230	0	0
7,360	Spikes, ...	$6\frac{4}{16}$	100	460	0	0
129,030	Cubic feet of ballast, ...	4	100	5,161	3	0
	Total for one mile of line laid with wooden-sleepers, weight per mile 373 tons, ...			31,054	15	9

7. The bearing surface of the

	square feet.
Greaves' bowl sleeper is, ...	$3{\cdot}1416 \times (1)^2 = 6{\cdot}28$
Denham's cast-iron	$2\frac{10}{12}' \times 1' \times 2 = 5{\cdot}66$
s' cast-iron	$3' \times 1' \times 2 = 6{\cdot}0$
,, ...	$7\frac{2}{12}' \times \frac{10}{12}' = 5{\cdot}97$*

The distance between the inner edges of the plates is :—

2′ 10½″ in the case of Denham's,

2′ 9″ ,, ,, Olpherts',

and the middle-space left unpacked in the pine-sleeper is $2\frac{10}{12}$ feet.

The distance between the *centres* of the points of attachment of the tie-bar of the Denham-sleeper is 3′ 2½″.

* This allows for the middle-space, which, being left unpacked, has no bearing surface.

8. In the following Table details are given regarding the passage of an engine over the experimental siding on the 6th, 10th and 12th November 1877 :—

No. of trial.	Date.	Speed of Engine in miles per hour at passage No.										Tons.			Cost of Repairs.
		1	2	3	4	5	6	7	8	9	10	No.	Engine.	Tender.	
															Rs. A. P.
1	6th Novr. 1877.	*	..	...	...	...	...	...	...	...	...	515	85¼	26	44 13 3
2	6th „ „	†	...	...	...	...	...	...	...	...	...	...	...	..	...
3	10th „ „	6	6	10	10	15	15	20	20	25	25	219	84	22	14 7 3
4	12th „ „	8	8	10	10	12	12	15	20	20	20	485	85¼	26	20 8 9
														Total Expenditure, ...	79 13 3

The total weight that passed over each sleeper, laid on formation-level, was—

$$= \left(\begin{matrix} \text{wagon tons} \\ 5 \times 15{\cdot}61 \end{matrix} \times 10 \left(\begin{matrix} \text{tons} \\ 56 \end{matrix} \times \begin{matrix} \text{tons} \\ 61{\cdot}5 \end{matrix} \right) \right) = 1314{\cdot}5 \text{ tons.}$$

After trial No. 1, no effect was observed.

After trial No. 2, it was noticed—

(1) that the bowl sleepers were unequally depressed;
(2) that the Denham-sleepers were much and unequally depressed;
(3) that the Olpherts-sleepers where depressed equally and to no great extent;
(4) that the pine-sleepers were not visibly depressed.

At the west end of the siding, after this passage, the locomotive was derailed, as regards one of the fore-wheels, by one of the hollow iron keys being crumpled by pressure. New rails were laid at each end of the experimental siding for several hundred feet.

Before trial No. 3, the line was inspected by passing over it on a trolly.

After trial No. 3, the conclusion arrived at, by inspection, was—

(1) that Greaves' bowl sleepers were most depressed;
(2) that the Denham-sleepers were depressed unequally and to an appreciable extent;
(3) that the Olpherts-sleepers were but slightly affected;
(4) that the creosoted pine-sleepers were not affected at all.

The line having been restored to a proper state, trial No. 4 was undertaken.

* A six-wheel coupled engine passed once at foot pace over the line.

† Five wagons, each laden with 200 cubic feet of clay, passed once at a foot pace over the line; the weight of each wagon, with its load, was 15·61 tons.

After the trial, it was observed—

(1) that Greaves' sleepers were appreciably disturbed;
(2) that the Denham sleepers were not quite so much disturbed;
(3) that the Olpherts-sleepers were not at all affected;
(4) that the pine-sleepers were not affected.

It may be proper here to observe that the tie-bar is attached in—

(1) the Denham-sleeper to points near the edges of the plates;
(2) the Olpherts-sleeper to the chair immediately below the rail.

Hence, though the Olpherts-sleeper, like the wooden sleeper, may depart from its true bedding, the gauge cannot alter.

In the Denham-sleeper any departure from the true bedding must involve a proportionate alteration of gauge.

9. In the following Table details are given as to the time and labour required to remove and to replace a sleeper and rail on formation-level :—

No. of trial.	Sleeper.	Time in minutes required to remove and replace		Time required to remove a rail only.	No. of men employed.	Date.	Tools actually used.
		a sleeper.	a rail.				
1	Greaves' iron bowl,	18	6	$2\frac{1}{2}$	5	13th November 1877.	4 spanners, 1 key-hammer, 2 crowbars, 1 small hammer, 1 chisel, 2 pickaxes.
2	The Denham, ..	$20\frac{1}{2}$	6	$2\frac{1}{2}$	5		4 spanners, 1 key-hammer, 2 pickaxes.
3	The Olpherts' fixed jaw inside,	$33\frac{1}{2}$	$14\frac{1}{4}$	$7\frac{1}{4}$	5		4 spanners, 1 key-hammer, 2 pickaxes.
4	The creosoted pine,	6	6	$2\frac{1}{2}$	5		2 augers, 2 key-hammers, 2 tree-nails, 2 chisels, 2 crowbars, 2 pickaxes.
5	The Olpherts' fixed jaw outside,	..	..	*$8\frac{42}{60}$	5	9' Jan. 1878.	

To take out a sleeper, the work to be done is, in the case of—

(1) Greaves' bowl sleeper—
To drive out 2 wooden keys.
„ „ 2 cotters and 2 gibs.
„ release the tie-bar.
„ excavate 2 holes, to release the 2 pots with their chairs.

* This was deduced from the time required when operating with *one* sleeper; if the experiment had been carried out with seven sleepers the (full complement to a rail), the time probably would have been less.

(2)

To drive out 2 woodon keys.
„ „ 2 cotters and 2 gibs.
„ prise 2 bearing-plates.
„ release the tie-bar.
„ excavate 2 holes to release the 2 bearing-plates.

(3) The Olpherts'-sleeper (moveable jaw outside)—
To unscrew $2 \times 2 \times 7 = 28$ chair nuts.
„ „ $2 \times 8 = 16$ fish-bolt nuts.
„ remove the outer jaws of $2 \times 7 = 14$ chairs.
„ excavate 2 holes, to release the 2 bearing-plates.

(4) The pine-sleepers—
To knock out 2 wooden keys.
„ wrench out $2 \times 2 = 4$ chair spikes.
„ knock 2 chairs sideways off the sleeper.
„ drag out the sleeper.

In each case, to replace the sleeper, the same work is required, in addition to packing the sleeper.

To take out a rail, the work to be done is—

(1) In the case of the Bowl, Denham, and Pine sleepers—
To remove the boxed-up ballast.
„ knock out 7 keys.
„ unscrew 8 fish-bolts.

(2) In the case of the Olpherts'-sleeper (outer jaw of chair moveable)—
To remove the boxed-up ballast.
„ unscrew $2 \times 7 = 14$ chair nuts.
„ „ 8 fish-bolts.
„ remove 7 half chairs (outer jaw).

(3) In the case of the Olpherts'-sleeper (inner jaw of chair moveable)—
To remove the boxed-up ballast.
„ unscrew 7 chair nuts.
„ remove 7 inner jaws of chairs by sliding them on the tie-bar.
„ unscrew 8 fish-bolts.

In each case, to replace a rail, the same work reversed is required.

The following observations may be of service:—

It took three minutes to drive out the cotter of the tie-bar (placed *flat*) of the Denham-sleeper; the proper time is one minute. When the tie-bar is on edge, the time required to drive out the cotter is half a minute.

When the fixed jaw of the chair is on the inner side of the rail, the Olpherts'-sleeper is very difficult to remove. The screw at each end of the tie-bar is $3\frac{1}{2}$ inches in length, of which $2\frac{1}{4}$ inches are actually taken up by the nut and check-nut at each end. This involves much work in screwing and unscrewing. It would be better to have cotters and to dispense with the screws and nuts.

10. In the following Table the result of several passages of an engine over the experimental siding on formation-level is shown:—

Nature of Sleeper.	19th November.			20th November.			21st November.			23rd November.			Total for 4 days.	
	Engine.			Engine.			Engine.			Engine.				
	Speed.	No. of passages.	Cost of repairs.	Speed.	No. of passages.	Cost of repairs.	Speed.	No. of passages.	Cost of repairs.	Speed.	No. of passages.	Cost of repairs.	No. of engine passages.	Cost of repairs
			Rs. A. P.			Rs. A. P.			Rs. A. P.			Rs. A. P.		Rs. A. P.
Bowl, ...	15 to 30 miles per hour.	48	12 0 0	15 to 20 miles per hour.	184	3 0 0	15 to 25 miles per hour.	...	1 12 0	15 to 25 miles per hour.	208	0 0 0	642	16 12 0
Denham, ...		...	6 0 0		...	0 12 0		...	0 8 0		...	0 0 0	...	7 4 0
Olpherts, ...		...	6 0 0		...	0 12 0		...	0 8 0		...	0 0 0	...	7 4 0
Fir, ...		...	2 8 0		...	0 8 0		...	0 4 0		...	0 0 0	...	3 4 0
			26 8 0			5 0 0			3 0 0			*Nil.*		34 8 0

The total weight which passed over each sleeper was 642 × 61 tons = 32,162 tons.

11. In the following Table, details regarding the time required to remove and to replace each kind of sleeper in ballast boxed-up, are given; the experiment was carried out on the 4th January 1878; the number of men employed in each case was five:—

Sleeper.	Minutes required.					
	To remove ballast boxed-up.	To remove the sleeper.	To replace the sleeper.	To pack the sleeper.	To box-up the ballast.	Total.
Greaves' iron-bowl, ...	$12\frac{55}{60}$	$4\frac{35}{60}$	$3\frac{35}{60}$	$7\frac{50}{60}$	$4\frac{40}{60}$	$33\frac{25}{60}$
The Denham, ...	$9\frac{40}{60}$	$20\frac{30}{60}$		$7\frac{20}{60}$	$5\frac{40}{60}$	$43\frac{10}{60}$
The Olpherts'—						
(*a*) fixed jaw outside of rail,...	9*	$4\frac{40}{60}$	16	$7\frac{20}{60}$	$5\frac{40}{60}$	$42\frac{40}{60}$
(*b*) „ „ inside „ ...	$9\frac{40}{60}$	$33\frac{30}{60}$		$7\frac{20}{60}$	$5\frac{40}{60}$	$56\frac{10}{60}$
Creosoted pine, ...	$8\frac{32}{60}$	6		$7\frac{20}{60}$	$5\frac{40}{60}$	$27\frac{32}{60}$

In regard to the Olpherts'-sleeper, in which the inner jaw of the chair is moveable, trouble was experienced in slipping the nut† and moveable jaw inwards along tie-bar to release the bed-plate. It would be better to use a cotter in place of the nut.

Two sleepers of the lighter kind of the Olpherts'-sleeper, which had lately been put into the experimental siding, were on this day (4th January) examined.

One sleeper had been in line from January to December 1877, or 12 months.
The other „ „ April to „ „ 9 „

These sleepers were perfectly sound and good.

* This should doubtless be $9\frac{40}{60}$.

† As the space between the longitudinal ribs of the upper surface of the bearing plate is limited, the nut would be more easy to work if it were not square, but hexagonal in form.

The weight of each plate of this lighter form of sleeper was 91 lbs.; of each plate of the sleepers, which had originally been placed in the siding, 131 lbs.

12. In the following Table details are given as to the price of different kinds of timber sleepers:—

Nature of Timber Sleeper.	Class.		
	Neuter.	First.	Second.
	Rs. A. P.	Rs. A. P.	Rs. A. P.
Teak, ...	...	5 0 0	
Sāl, ...	4 8 0 5 8 0	...	4 0 0
Fir—			
10′ × 10″ × 5″	3 7 2·9	...	3 3 6·2
9′ × 10″ × 5″	...	2 14 9·4	
Iron-wood, ...	...	5 0 0	
Assan-wood, ...	...	4 0 0 4 4 0	
Srish „	...	4 0 0 4 4 0	
Mowah „	...	4 8 0	
Red gum „	...	5 0 0	
Jarrah „	...	5 8 0	

This information was obtained from the Chief Auditor, East Indian Railway, in reply to a demi-official letter of 19th September, 1877.

13. In the following Table, details are given regarding the passage of Engine No. 490 over the experimental siding. During each passage the speed of the engine was 30 miles per hour; the first excursion was made on the 7th January 1878:—

	7TH.		8TH.		9TH.		10TH.		11TH.		12TH.		14TH.		TOTAL FOR 7 DAYS	
	No. of Engine passages.	Cost of repairs.	No. of Engine passages.	Cost of repairs.	No. of Engine passages.	Cost of repairs.	No. of Engine passages.	Cost of repairs.	No. of Engine passages.	Cost of repairs.	No. of Engine passages.	Cost of repairs.	No. of Engine passages.	Cost of repairs.	No. of Engine passages.	Cost of repairs.
		Rs. A. P.		Rs. A. P.		Rs. A. P.		Rs. A. P		Rs. A. P.		Rs. A. P.		Rs. A. P.		Rs. A. P.
Greaves' bowl, ...	174	0 15 6	176	1 7 0	170	1 7 3	186	0 15 6	190	0 7 9	192	1 15 0	202	...	1,290	7 4 0
Denham, ...	...	...	...	0 7 9	...	...	...	0 7 9	...	0 7 9	..	...	...	...	...	1 7 3
Olphert's, ...	...	...	...	0 7 9	...	...	...	0 7 9	...	0 7 9	...	...	...	...	...	1 7 3
Creosoted pine, ...	...	0 15 6	..	0 7 9	...	...	...	...	...	...	...	...	...	...	...	1 7 3
No. of bowls { cracked,	10	32 0 6	*2	6 6 6	2	6 6 6	4	12 13 0	1	3 3 3	3	9 9 9	6	19 3 6	...	89 11 0
No. of bowls { broken,...	1	3 3 3	...	...	...	...	†3	...	...	...	...	...	‡1	...	...	4 3 3
TOTAL COST Rs.,	...	37 2 9	...	9 4 9	...	7 13 9	...	14 12 0	...	4 10 6	...	11 8 9	...	19 3 6	...	104 8 0

* On the curve from main line to the siding at each end, it was found necessary to put in a tie-bar to every bowl-sleeper. In the case of the Denham- and Olpherts'-sleepers, this also would be necessary on a curve. *See* para. 21.

† These 3 bowls were cracked on the 7th January and then valued.

‡ This bowl was cracked on the 7th January and then valued.

Out of 175 pairs (or 350) bowls laid down, in 7 days of 8 working-hours each, the total number of bowls cracked is 28.

broken is 5, of which 4 were previously cracked.

	Tons.	cwt.	qrs.
The weight of engine No. 490 that ran to and fro 1,290 times is	35	10	0
" tender, " "	26	0	0
Total tons, ..	61	10	0

The total weight that passed over each sleeper, at 30 miles per hour, is 1,290 × 61¼ tons = 79,335 tons.

14. On the 13th November 1877, the time required to remove and replace a rail on formation-level was found; and on the 15th January 1878, the time required to remove and replace boxed-up ballast was found. The number of men employed was in each case five.

The details are given in the following Table :—

Nature of Sleeper-Road.	TIME IN MINUTES REQUIRED.					
	BOXED-UP BALLAST.		A RAIL.*		TOTAL.†	
	To remove.	To replace.	To remove.	To remove and replace.	To remove a rail.	To remove and replace a rail.
Greaves' bowl, ...	$\frac{57}{60}$	$1\frac{15}{60}$	$2\frac{1}{2}$	6	$3\frac{27}{60}$	$8\frac{12}{60}$
Denham, ...	$\frac{57}{60}$	$1\frac{15}{60}$	$2\frac{1}{2}$	6	$3\frac{27}{60}$	$8\frac{12}{60}$
Olpherts'—						
a. Fixed jaw inside, ..	3	$2\frac{25}{60}$	$7\frac{1}{4}$	$14\frac{1}{4}$	$10\frac{15}{60}$	$19\frac{40}{60}$
b. „ „ outside, ..	..	..	$8\frac{43}{60}$	..	$11\frac{43}{60}$	..
Creosoted pine, ...	$\frac{57}{60}$	$1\frac{15}{60}$	$2\frac{1}{2}$	6	$3\frac{27}{60}$	$8\frac{12}{60}$

15. On the 15th January 1878, four breaches, each 100 feet in length (*i. e.*, the length of 5 rails), were begun, one in each length of sleeper road.

The following Table gives details regarding the making of the four breaches :—

	PLATELAYER'S WORK TO REMOVE 100 FEET OF PERMANENT-WAY.			EARTHWORK, &c. TO MAKE THE EXCAVATION.				GRAND TOTAL.	COST.		
	Minutes.	Men	Men, hours.	Hours.	Minutes.	Men.	Men hours.	Men, hours.	Of removing 100 feet of Permanent-way.	Of making Excavation.	TOTAL.
									Rs.	Rs.	Rs.
Greaves' bowls, ...	35	15	8·75	13	0	50	650	658·75	0·30	20 31	20·61
Denham, ...	31	15	7·75	14	0	50	700	707·75	0·66	21·90	22·56
Olpherts', ...	91	15	22·75	8	25	25	488	510·75	0·72	15·25	15·97
				9	32	32					
Creosoted pine, ...	40	15	10·0	9	0	50	450	460·00	0·38	14·10	14·48
									2·06	71·56	73·62

* This is the time required for handling the rail; it does not include the time of dealing with the

† This includes all labour in setting the rail properly in its place in boxed up ballast.

In making these four breaches, the following work was done :—

(*a*).—In each of the four breaches—

$$\frac{13' \times 15'}{2} \times \frac{15}{12} \times 100' = 1{,}750 \text{ cubic feet of ballast}$$

$$16' \text{ wide} \times 11\tfrac{10}{12} \text{ deep} \times 100' = 2{,}933 \quad \text{„} \quad \text{„} \quad \text{earth}$$

were removed.

(*b*).—In the case of the :—

(1) Creosoted pine-sleepers,
(2) Denham-sleepers,
(3) Greaves' bowl-sleepers,

the keys were knocked out, the fish-plates released, and the sleepers (complete) dragged out.

(*c*).—In the case of the Olpherts' sleeper—

the check-nuts were taken off; the true-nut was unscrewed sufficiently to allow the lower table of the rail to pass between the jaws of the chair, and then screwed up to allow room for the check-nut which was re-screwed to prevent its being lost.

The rails being laid on one side, the sleepers (complete) were dragged out.

In each case the permanent-way and ballast were placed on the east side of the way, and the earth excavation on the west side.

16. *Fig.* 4 shows the section which should be given to the ballast. The following details may be of service :—

5 inches is the depth of the rail.
20 inches is the depth from rail to formation-level.
15 „ „ of ballast from formation-level to base of rail.
13 feet is the width of ballast at top.
15 „ „ „ bottom.
8 inches is the depth of ballast below a pine-sleeper or Greaves' bowl-sleeper.
12 „ „ „ Denham's or Olpherts'* sleeper.

17. On the 17th January 1878 the refilling of the four breaches was begun.

The following Table gives details :—

* Mr. Olpherts claims that ballast may be saved by the use of his sleeper. If ballast 8 inches in depth only be given, as in the case of the pine sleeper, there would be a saving of 4 inches of ballast in depth. See the estimate of cost, para. 5.

Nature of Sleeper-Road	Platelayer's work under Mr. Perry.										Earthwork and relaying of ballast under Mr. Doran.										Grand total of work done in repairing the breaches.	
	To link-in 100 feet of permanent-way.				To pack 100 feet of permanent-way.				Total.		To refill with earth and beat down to formation-level.				To relay ballast for the sleepers.				Total.			
	Hrs.	M.	Men.	Rs.	Hrs.	M.	Men.	Rs.	Men, hrs.	Rs.	Hrs.	M.	Men.	Rs. †	Hrs.	M.	Men.	Rs. †	Men, hrs.	Rs. †	Men, hrs.	Rs.
Greaves' bowl,	1	45	15	0·89	9	15	15	4·74	165	5·63	10	...	50	15·6	6	30	41	8·3	766·5	23·9	931·5	29·53
Denham,* ...	1	45	15	0·88	9	15	15	4·67	165	5·55	10	...	50	15·6	7	30	21	4·9	657·5	20·5	822·5	26·05
Olpherts',* ...	2	45	15	1·31	7	15	15	3·46	150	4·47	7	...	50	10·9	6	30	41	8·3	616·5	19·2	766·5	23·67
Creosoted pine,	1	15	15	0·71	6	45	15	3·84	120	4·55	8	45	50	13·7	3	30	49	5·4	609·0	19·1	729·0	23·65
									600	20·20									2649·5	82·7	3249·5	102·90

* Referring to paragraph 16 of this note, it will be noticed that the platelayer had more than his fair share of work to do in regard to the ballasting of the Denham and Olpherts' sleepers. For the Clerk of Works (Mr. Doran) put on the road—

7 inches of ballast only, instead of 12 inches in the case of the Denham sleeper.

10 „ „ „ 12 „ „ Olpherts' „

† The rate of labour under Mr. Doran was 4 annas per working day of 8 hours, per man.

18. The four breaches having been repaired, engine No. 490 ran to and fro at a speed of 30 miles per hour over the siding on the 21st, 22nd and 23rd January 1878. The following Table gives details :—

	21ST.		22ND.		23RD.		TOTAL FOR 3 DAYS.	
	No. of engine passages.	Cost of repairs.	No. of engine passages.	Cost of repairs.	No. of engine passages.	Cost of repairs.	No. of engine passages.	Cost of repairs.
		Rs. A. P.		Rs. A. P.		Rs. A. P.		Rs. A. P.
Greaves' bowl, ...	142	1 7 6	200	0 15 6	200	0 7 6	542	2 14 6
Denham, ...	..	0 15 6	..	0 15 6	..	0 7 6	..	2 6 6
Olpherts', ...	..	0 11 6	..	0 15 6	..	0 7 6	..	2 2 6
Creosoted pine, ...	..	0 15 6	..	0 15 6	..	0 7 6	..	2 6 6
		4 2 0		3 14 0		1 14 0		9 14 0

Total weight that passed over each sleeper = 542 × 61½ tons = 33,333 tons. Where the breaches had been made, the road sank chiefly on that part laid with bowl-sleepers.

In this instance, as in the case of the engine-passages recorded in paragraphs 8, 10 and 14, it was noticed that the Denham-sleeper laid on brick ballast had a decided tendency :—

a, to depart horizontally from a position at right angles to the rail.

b, to tilt in a vertical direction.

This was more especially the case with those sleepers that had no tie-bar.

19. The total cost of the experiments which began on the 6th November 1877, and ended on the 23rd January 1878, is given in the following Table :—

	AMOUNT.		
	Rs.	A.	P.
Making and remarking the siding. *See* Table II., ...	2,985	12	6
Greaves' bowl-sleeper bowls, cracked or broken, 29 in number. *See* paragraph 13, ...	93	14	3
Engine hire for,—			
6th, 10th, 12th, 19th, 20th, 21st and 23rd November 1877, ...	..	..	..
7th to 12th, 14th, 21st to 23rd January 1878, ...	..	..	..
A total of 17 days (*see* paras. 8, 10, 13, and 18), at Rs. 20 per diem,	340	4	0
Total Rs, ..	3,419	10	9

20. The statements which have been made in the preceding paragraphs may now be summed up :—

	Nature of Sleeper.				Authority.
	Greaves' bowl.	The Denham.	The Olpherts'.	Creosoted pine.	Paragraphs.
Number of passages made by a locomotive over rails on formation-level,	662	662	662	662	8—10
Damage in rupees done by the locomotive in passing over formation-level,	$16\frac{12}{16}$	$7\frac{4}{12}$	$7\frac{4}{12}$	$3\frac{4}{12}$	10
Number of passages made by a locomotive over rails on sleepers packed on ballast,	1,832	1,832	1,832	1,832	13—18
Damage in rupees done by the locomotive in passing over the ballast.	*$104\frac{3}{64}$	$3\frac{55}{64}$	$3\frac{39}{64}$	$3\frac{39}{64}$	13—18
Weight in tons that passed over the rails laid on sleepers on formation-level,	40,476·5	40,476·5	40,476 5	40,476·5	8—10
Weight in tons that passed over the rails laid on sleepers on ballast,	112,668	112,668	112,668	112,668	13—18
Weight of sleeper in lbs.,	213·59	235	285	173·45	3, 4, 5, 6
Time in minutes required to remove a rail in boxed-up ballast,	$3\frac{27}{60}$	$3\frac{27}{60}$	$10\frac{15\dagger}{60}$ and $11\frac{45\ddagger}{60}$	$3\frac{27}{60}$	14
Time in minutes required to remove and replace a rail in boxed-up ballast,	$8\frac{12}{60}$	$8\frac{21}{68}$	$19\frac{40}{60}$	$8\frac{12}{60}$	14
Time in minutes required to remove and replace a sleeper in boxed-up ballast,	$33\frac{25}{60}$	$43\frac{10}{60}$	$56\frac{40\dagger}{60}$ and $42\frac{40\ddagger}{60}$	$27\frac{32}{60}$	11
Time in minutes required to remove 100 feet of permanent-way,	35	31	91	40	15
Time in hours required to link-in 100 feet of permanent-way,	$1\frac{45}{60}$	$1\frac{45}{60}$	$2\frac{45}{60}$	$1\frac{15}{60}$	17
Time in hours required to link-in and pack 100 feet of permanent-way,	10	10	10	8	17
Cost of a sleeper *complete* with chairs and keys	Rs. A. P. *a* 8 3 2	Rs. A. P. *a* 8 0 0	Rs. A. P. *b* 10 15 $11\frac{1}{2}$	Rs. A. P. *c* 6 13 0	*a* Table I. *b* 5 *c* 6
Cost of one mile of way complete,	*d* 33,590	*e* 35,986	*f* 34,907§	*g* 31,055	*f* 5; *g* 6 *d* 3; *e* 4

* This is due to the number of cracked and broken bowls, it will be noticed that, on formation-level, no bowls were cracked or broken. In regard to this circumstance, attention is invited to Table III. of this Note.

† Fixed jaw of chair inside of the rail.

‡ Fixed jaw of chair outside of the rail.

§ This estimate allows for a tie-bar to every *alternate* sleeper; taking into account curves, and the diminution of strength in the tie-bar, caused by cutting holes for cotters it is probable that a tie-bar to *each* sleeper will be required. If a tie-bar be given to *each* Olpherts' sleeper, and the full section of ballast, as in the case of all the other sleepers, the cost per mile (with Olpherts' sleepers) will be Rs. 39,469. See page 6

21. It may now fairly be stated that—

a. The creosoted pine-sleeper is the best form of sleeper of all; but having regard to the difficulty of procuring it, and to its comparatively short life, it has to be rejected:

b. The bowls, when placed either on earth or on ballast, give trouble in packing; when laid on ballast, they are liable to break: against this must be considered the statement in Table III, regarding the small renewals of this kind of sleeper, when placed on loam, as compared with timber sleepers.

c. The Denham and Olpherts' sleepers, as has been shown, are of the same nature: the Olpherts' has, however, one great advantage over the Denham, in that the tie-bar seizes the *chair*, and not the *plate*—see paragraph 8. The extra time required, in the case of the Olpherts', to remove and replace a rail, or sleeper, is shown in paragraph 20:

d. The Olpherts' sleeper is, after the creosoted pine-sleeper, the best of all in places where liability to accident is small; the only objection to it is the time taken in handling it; see paragraph 20. The sleeper is scientifically designed and makes a good steady road.

A tie-bar is required to every sleeper, whether of the Denham, or Olpherts', pattern:—

(1) on a curve, if nuts be used as at present.

(2) everywhere if the nuts being discarded, the tie-bar be weakened by cutting in it holes for cotters and gibs.

TABLE I.

East Indian Railway.

Statement showing the weight and cost of permanent-way articles.

Names of Articles	Rate				Weight, &c.
	Unit.	Rs.	A.	P.	
Chairs, middle, N. S.	each	0	12	0	24½ lbs. each.
„ „ O. S.	„	0	12	0	22¼ „ „
„ end or joint	„	2	2	0	14 „ „
Spike, English, plain and twisted ..	100	9	5	0	1 „ „
„ „ O. S.	„	9	5	0	1¼ „ „
„ country, of sorts	„	6	0	0	Condemned patterns.
Bolts, and nuts, fish-plate, N. S. ..	„	18	8	0	1 7/32 lbs. each.
„ „ O. S. ..	„	16	8	0	1 1/16 „ „
Keys, middle	1,000	50	0	0	
Sleepers, ashpit	foot	2	0	0	
„ creosoted (square or triangular)	each	5	0	0	
„ cast-iron, Greaves' bowl ..	„	3	3	3	One bowl, each 86 lbs.
„ „ „ tie-bar ..	„	1	10	8	Rs. 5 1/8 per cwt.
„ „ „ gibs and cotters	„	0	0	6	„ 4½ „ „

Statement showing the weight and cost of permanent-way articles (Continued).

Names of Articles	Rate				Weight, &c.
	Unit	Rs.	A.	P.	
Sleepers, cast-iron Barlow's flat, ..	each	3	0	0	Each 114 lbs.
„ crossing (any tie-bar), ..	„	5	8	0	
„ „ gum (Australian),	„	4	0	0	
„ „ country, ..	„	3	0	0	
„ „ iron-wood, ..	„	6	0	0	
„ „ sāl, ..	„	4	0	0	
„ „ teak, ..	„	5	0	0	
Denham's C. iron-plate sleepers, ..	„	8	0	0	2 bearing plates, 1 tie rod, 2 gibs, 2 cotters, 4 bolts and nuts. The Royalty has not yet been fixed.
Fish-plates, N. S. ..	„	0	10	0	$10\frac{1}{2}$ lbs. each.
„ O. S.	„	0	14	0	$13\frac{1}{16}$ „ „
Rails, N. S., average	foot	1	1	6	73 lbs. per yard.
„ O. S., ...	„	1	4	4	82 „ „
„ „ 24 feet, ...	each	30	2	0	82 „ „
„ „ 23 „	„	28	12	0	82 „ „
„ „ 22 „	„	27	15	4	82 „ „
„ „ 21 „	„	26	4	0	
„ „ 20 „	„	25	2	0	
„ „ 19 „	„	24	2	4	
„ „ 18 „	„	22	10	0	
„ „ 17 „	„	21	6	0	
„ „ 16 „	„	20	1	0	
„ „ 15 „	„	18	12	0	
„ „ 14 „	„	16	11	0	
„ N. S., 23 „	„	25	3	0	73 lbs. per yard.
„ „ 22 „	„	24	1	0	73
„ „ 21 „	„	22	15	6	73 „ „
„ „ 20 „	„	21	14	0	73 „ „
„ „ 19 „	„	20	12	6	73 „ „
„ „ 18 „	„	19	11	0	73 „ „
„ „ 17 „	„	18	10	0	73 „ „
„ „ 16 „	„	17	8	0	73 „ „
„ Bridge, heavy, ...	foot	1	2	0	70 „ „
„ „ light, ...	„	0	11	1	45 „ Other sizes Rs. 100 per ton.
„ Barlow's saddle, 18 feet, ..	„	33	0	0	98 lbs. per yard ; Rs. 130 per ton, or Rs. 1-3-9 per foot.
CROSSINGS.					
English or country, 1 in 7, ..	Set	105	0	0	1 in $7\frac{1}{2}$; $8\frac{1}{2}$; 9.
„ „ 1 in 10, ..	„	125	0	0	1 in $10\frac{1}{2}$; 12.
Ransome's patent plate, ...	„	135	13	3	No chairs required.
Chairs A, B, C, D, plain, ..	each	4	8	0	
„ check, E and F, ...	„	1	0	0	Ordinary crossings are complete with—
„ fish-plates D, ...	„	11	0	0	2 wing plates.
„ of sorts, country, ...	„	2	6	0	2 check rails.
„ level, crossings, ...	„	3	4	0	1 point rail. each.
Rail-wing, ...	„	30	0	0	A, B, C, D chairs, one
„ under 20 feet, ...	„	20	0	0	2 fish-plate chairs.
„ points, ...	„	40	0	0	4 E chairs.
„ check under 10 feet, ..	„	10	0	0	In some cases, a chair is
„ „ over 12 „ ..	„	15	0	0	omitted.

Statement showing the weight and cost of permanent-way articles (Continued).

Names of Articles	Rate				Weight, &c.
SWITCHES.	Unit.	Rs.	A	P.	
Switch-box with brackets, balls weight, brass bushes, wrought-iron lever connecting rods, pins, sc bolts (fitted oval or square), com plete, ...	each	50	0	0	
Switch, 3 throw, English or country complete, ...	set.	270	0	0	This contains 2 stock rails, 4 tongue rails, 2 heel chairs, 10 slide chairs, rods and bolts.
Switch, single, English, Ashburny's complete, ...		124	4	0	This contains 2 tongue rails, 2 heel chairs, 8 slide chairs, rods and bolts.
Switch, single, English or country, complete, ...		270	0	0	This contains 2 tongue rails, 2 stock rails, 8 slide chairs, 2 heel chairs, rods and bolts.
Switch-box, oval or square, ...	each	24	0	0	
„ handle, ...		3	0	0	
„ weights, ...		1	0	0	
„ dark, ...		3	0	0	
„ connecting rods, .		3	0	0	
„ brass bushes, .. .		1	0	0	
Switch-rails, stock or back ; right o left : English or country, ...		30	0	0	
Switch-rails, tongue, ...		30	0	0	
„ Ashburny's, ...		36	0	0	
„ chair toe, O. P., ..		2	0	0	
„ heel (right or left), ..		5	0	0	
„ „ Ashburny's, ..		7	8	0	
„ slide, ordinary, ..		2	2	0	
„ „ Ashburny's, ..		3	3	0	
Bolts for switch-chairs, ...		0	4	0	
„ locking switch with cotter,		0	6	0	
Sleepers, Barlow's, cast-iron, with angle-iron tie-bar, ...	ton	120	0	0	lbs. each pair.
Hollow iron keys, 5 inches, ...	each	0	2	9	
„ „ 6 „		0	3	0	
„ „ 8 „		0	4	0	

TABLE II.

East Indian Railway.

Main Line.

Statement of the cost of making and remaking the siding (2,000 *feet in length*) *for the experiments with sleepers.*

Details.	Quantity.	Rate.		Amount.
		Rs.	Unit.	Rs. A. P
Earthwork, ...	155,363 c. f.	..	..	681 12 3
Breaking ballast, ...	33,185 c. f.	1	100	331 14 0
Dressing formation level, ..	30,380 s. f.	3	100	91 2 3
Levelling earthwork, ...	..	..	..	36 13 6
Laying the road, ...	..	..	..	162 4 9
Lifting and packing, .. .	..	..	..	174 14 6
Supplying 100 hammers, ..	2½ mds	17/6	maund	43 7 0
Tool handles, ...	..	..	..	6 4 0
Loading, unloading, spreading, and dressing ballast, ..	38,133 c. f.	1/4	100	476 10 6
Loading, unloading, spreading, and dressing rubbish, ..	7,308 c. f.	1/4	100	91 5 6
Repairing siding, ...	..	..	..	171 7 3
„ breaches, ...	..	..	..	114 5 3
Breaking, spreading, and levelling *khoa*, ...	..	..	..	152 14 6
Breaking, removing, and spreading *khoa*, ...	..	..	..	189 11 6
Total				2,714 14 9
Add superintendence, at 10 per cent., ...				270 13 9
Grand Total, ..				2,985 12 6

TABLE III.

Eastern Bengal Railway.

Statement showing the renewals of timber and cast-iron bowl-sleepers during a period of eleven half-years.

Half-year ending	Timber sleepers				Bowl-sleepers, each bowl weighing 92lbs				Remarks
	Total	Age in Years	Removed	Per cent	Total (pairs)	Age in Years	Removed (pairs)	Per cent	
June 1872 ..	344,031	7·65	5,168	1·50	15,474	1·98	119·5	0·77	These cost-iron bowls are *not* laid in ballast, but on ordinary loam. They are at first packed with a wooden tool, in form like a pickaxe ; and the final packing is effected by ramming with wooden rammers through the holes in the upper part of the bowl.
December „ ..	341,648	7·97	4,893	1·43	15,474	2·47	30·5	0·19	
June 1873 ..	347,256	8·06	8,488	2·44	15,500	2·95	87·0	0·56	
December „ ..	340,908	8.23	9,500	2·78	15,500	3·44	53·0	0·34	
June 1874 ..	340,908	7·98	20,296	5·95	15,500	3·89	199·0	1·28	When the iron bowls are taken up, it is found that the earth adheres closely to the under surface of the bowl.
December „ ..	351,752	7·72	13,588	3·86	15,500	4·38	21·5	0·13	The Superintendent of Way and Works considers that the bowls most often get injured in the process of being packed (especially when an iron tool is used), and that the concussion of passing trains causes fracture.
June 1875 ..	350,486	8·05	4,624	1·31	15,118	4·82	196·0	1·29	
December „ ..	348,076	8·22	9,042	2·59	15,033	5·31	9·0	0·05	
June 1876 ..	351,965	8·08	14,130	4·0	14,554	5·73	182·0	1·25	The bowl-sleeper-road is put into good order before the rains ; during the rainy season, very little is done to it.
December „ ..	350,497	8·24	7,864	2·24	14,237	6·22	14·5	0·10	The ratio of the $\frac{\text{number of creosoted pine-sleepers}}{\text{number of sleepers of other timber}} = \frac{1}{1{\cdot}11}$ nearly.
June 1877 ..	349,750	8·23	10,990	3·14	14,237	6·59	269·0	1·88	
Total ..	3,817,277	..	108,583	31·25	166,127	..	118·1	7·84	On the East Indian Railway, packing is effected with an ordinary pickaxe.
Average of eleven half-years ..	347,025	..	9,871	2·84	15,102	..	107·	0·71	The line of fracture runs from the rim of the bowl through a packing hole, and sometimes through a tie-bar hole. Mr. Rendel, Consulting Engineer to the East Indian Railway Company, considers the double pot-sleeper, used on the Great Indian Peninsula Railways, the best of its kind.

TABLE IV.

Showing Mr. Denham's own Estimate *of the cost of one mile of way laid with his sleepers.*

Cost of Denham sleeper incomplete.									Cost per mile of way laid with Denham sleepers.				
Details.	Weight in lbs.	Rate.				Cost of one sleeper incomplete.			Number.	Details.	Value.		
		Unit.	RS.	A.	P.	RS.	A.	P.			RS.	A.	P.
2 Bearing plates, Cast-iron, ..	163½	ton.	77	12	0	5	10	9	460	Rails, ...	12,540	0	0
1 Tie-bar, Wrought-iron, ..	12½	„	120	0	0	0	10	8	1,840	Sleepers, at Rs. 7-1-9, ...	13,081	0	0
2 Keys, „ „ ..	2½	„	200	0	0	0	3	7	920	Fish-plates, ...	575	0	0
4 Bolts and nuts, „ „ ..	5	„	160	0	0	0	5	9	1,820	Bolts, ...	230	0	0
2 Wooden cushions, ...	..	..	..	..	..	0	3	0	3,680	Chairs, ...	2,760	0	0
Cost of one sleeper, without chairs, gibs and cotters, Rs. ..						7	1	9	96,722	c. f. ballast, ...	3,868	14	0
										Cost per mile of way, Rs. ...	33,054	14	0

Mr. Denham considers that the two bearing plates of his sleepers should not together exceed 137½ lbs.; at Howrah, they weighed 163½ lbs.; and it was officially stated that the sleeper (including bolts and nuts, but excluding chairs) cost Rs. 8 each.

This estimate is less than that given in pages 3 and 4 (333 and 334); but, it may be observed that, [chairs and gibs and cotters being omitted] the estimate is inaccurate; it is assumed that less than the full quantity of ballast (1,29,030 c. f.) may safely be used. The statement is given in fairness to Mr. Denham.

ON EXPERIMENTS WITH SLEEPERS AT HOWRAH ON THE E. I. RAILWAY.

Scale. 1 *foot* = 1 *inch.*

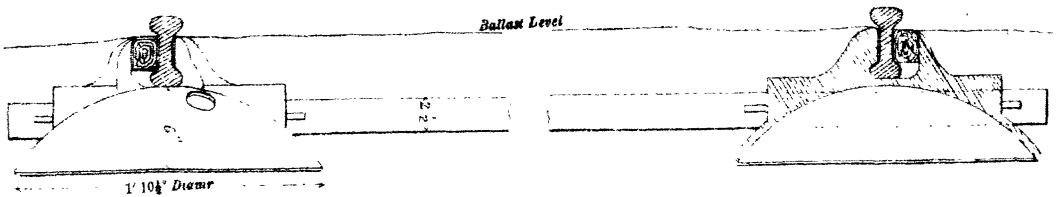


Fig. 1.
GREAVES' SURFACE PACKED
IRON RAILWAY SLEEPERS.

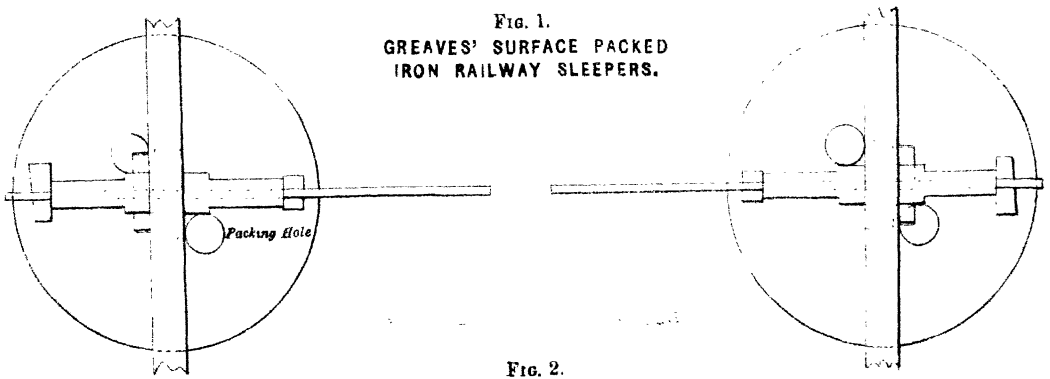
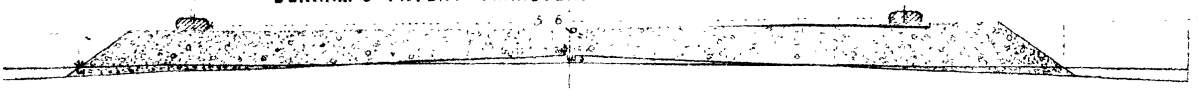


Fig. 2.
DENHAM'S PATENT TRANSVERSE CAST-IRON SLEEPER.



No. CCLXXX.

REPORT ON THE DEFENCE WORKS IN THE RIVER INDUS AT KHARAKWALAH IN THE DERA GHAZI KHAN DISTRICT, FROM DECEMBER 1876 TO MAY 1877.

[*Vide* Plates I., II. and III.]

By T. E. Ivens, Esq., C.E., *Executive Engineer, Dera Ghazi Khan Division, Indus Canals.*

The changes that occurred in the bed of the River between 1874 and May 1877, are shown in *Plates* I. II. and III.

Account of the river and its erosion since 1874.—The cutting action of the river on its right bank about the village of Tranda commenced in December 1874, and continued with more or less violence till February 1877, oscillating between points opposite the Kharakwalah Chauki and the head of the Shoria Canal. The great inundation *band* was reached and cut into in July 1875, the spill water being kept back and prevented from spreading in all directions over the country by the Kote Daud *band* which had been raised the previous cold weather.

River Works at Kaluwalah, results and subsequent plans.—In the working season of 1875-76 the erosion below Kharakwalah still continuing, defence works in the river were started opposite the village of Kaluwalah with the object of turning the direction of the main stream on to its left bank and thus reducing the violence of the current below Kharakwalah. These works, however, did not in the main prove successful, and the erosion continuing with unabated violence, the idea, as first proposed

of constructing another *band* at the back of that of the Kote Daud was laid aside, and it was determined to run out a series of solid spurs from the right bank of the river starting from sites on the bank a little on the up-stream side of the points of impact of the several streams which together formed the main current of the river.

Spur No. I.—Operations were commenced in November 1876 on three main spurs. The first started from the end of the great inundation *band* and ran across a creek to a distance of 400 feet. This creek flowed at the time with a small velocity, of about $1\frac{1}{2}$ feet per second, between the hard bank and a succession of sand banks or islets running north and south. At 400 feet the main stream was reached, here the current was $2\frac{1}{2}$ feet per second.

Spur No. II.—Spur No. II. left the bank at a point 2,200 feet below No. I., here the current was running at the rate of 6 to 7 feet per second the depth of water being from 16 to 20 feet. When work was commenced the erosion was here more violent than at any other part of the river bank, but the spur most effectually checked it and prevented what otherwise would have been the case, the outflanking of the third spur on its upper side.

Spur No. III.—Spur No. III. was built 3,800 feet below No. II. and 1,600 feet below the end of the loop line *band* as it then was, the river running at a velocity of 6 feet per second the depth of water being from 16 to 18 feet.

Spurs Nos. 1a and 2a, and date of commencing work.—Subsequently two smaller Spurs numbered 1*a* and 2*a* were also run out, the former between the main Spurs Nos. I. and II. 780 feet below the former, the latter starting from the end of the loop line *band*. These several works were commenced, the main ones, No. I. on the 22nd December, 1876, No. II. on 4th January, No. III. on the 13th December, and were run out to lengths respectively of 430, 120, and 160 feet long. The smaller Spur No. 1*a* was commenced on the 17th February, No. 2*a* on 29th December, their lengths were 30 feet and 50 feet respectively.

Total length of spurs.—The aggregate length was therefore 790 feet, of this Spur No. I. is classed separately, the conditions as to depth of water and velocity being different from the other four. In the former, it is mentioned above, the velocity was only $1\frac{1}{2}$ feet per second, the maximum depth of water being only 10 feet, the minimum at both ends nil.

With the other spurs the mean depth was from 16 to 20 feet and velocity of 5 to 7 feet per second equal to $3\frac{1}{2}$ to 5 miles per hour. Of the aggregate 790 feet therefore 360 belong to the first class, 430 in Spur No. I. to the second class.

Mode of constructing spurs.—The mode of operation in constructing the spurs was as follows:—The site and direction having been chosen, the latter averaged between 110° and 120° with the stream, trees of the largest size that could be obtained with all their branches and leaves untouched were thrown over, at first from the bank, afterwards as the work progressed from off the sides of boats. The trees were all cut and dragged to the site of the works from the adjoining fields, which most fortunately were very wooded and thereby the work was done at a moderate cost, the amount of compensation paid being only Rs. 255. This of course is a mere fraction of what the trees would have cost had they been paid for, over 2,500 trees of all sizes having been cut. The above award was given for trees that grew near wells or near gardens and which the people were loth to part with. No doubt the object for which the trees were wanted, had a great deal to do with their having been obtained for nothing, the ground from which they were cut being that which it was desired to protect.

Trees.—The trees having been cut they were brought to the site of the work by bullocks, as many pairs as were required being yoked to each tree, ranging between one pair to two small trees, to as many as a maximum of 16 pairs to one tree, some of the largest being 25 to 35 feet in height. Altogether 6,400 pairs of bullocks were worked at a total cost of Rs. 3,200, this forms the heaviest sub-head, being rather more than one-fourth of the total expenditure.

How loaded.—The tula, tamarisk, was the tree most extensively used, a few shisham, kikar, ber and others were also brought down, but in very small numbers. The tree was next loaded, this was done by means of a net lashed to the trunk of the tree at the point of its centre of gravity, more or less, the net was then filled with stones suitable to the weight and size of the tree, the maximum weight of the stones for one tree being 30 to 35 maunds. The tree was then thrown over into the water a little up-stream of the place where it was desired that it should lie when reaching the bottom, this of course depended on the strength of the current.

Stones.—The stones were brought from the Sori torrent about 12 miles off. The average weight of one was from 30 seers to one maund, they were brought on camels at a total cost of Rs. 1,621, for this sum nearly 34,500 maunds of stone were carried, this gives an average weight of stone on each tree of 14 maunds.

Superstructure.—This process continued until the trees began to show out of the water, on the top of them were placed smaller trees, large branches and layers of brushwood, until a fairly even surface was obtained from 3 to 5 feet. Above water surface, this layer which necessarily was a loose mass was then weighted down with long and heavy trunks of trees without their branches, the logs being laid on until the upper side of the layer had settled down to a level with the water. The process was again repeated, and layers kept on being built up until the mass had finally consolidated. Instead of trunks of trees, sand bags were in some cases used, they served very well to form the top roadway, once all settlement had ceased, and the bag of sand was not likely to be reached by the water. The length of the bags were $3\frac{1}{2}$ feet, so that two bags placed lengthways across the spur formed a convenient roadway of 7 feet. The bags when full contained 5 cubic feet of sand weighing about $3\frac{1}{4}$ maunds, it was not pure sand but was partly mixed up with clay, 500 bags were thus used at a cost of Rs. 175.

Mode of construction, continued.—As the foundations appeared above water, and the top layers and roadway of the first section were being formed, the work of advancing the foundations ahead progressed, but the loaded trees, instead of being launched from the end of the spur or pier, were taken out in boats and thrown overboard, the boat being brought into position by means of two cables, one on shore, one fastened to a buoy anchored at some convenient place in mid-stream.

Unloading the boats.—No particular means were used in discharging the boats of their cargo of weighted trees. A projecting platform was at first tried resting on the side of the boat, which also served as an axis, the platform being made to tilt over, when it was desired to drop the tree. But the trees varied so much in size, and with their branches took up so much room that the original plan was found the most convenient, that of placing the tree across the boat, the trunk being inwards and the middle of the tree resting on the boat's side, so that at a given signal and without any trouble the whole mass could be thrown over.

Spur No. III.—The first Spur undertaken was No. III., the conditions of the river being as mentioned in page 2. In four days a length of 100 feet had been made up to the water level, the average width being 22 feet and depth of water of 18 feet making a total cubical content of 40,000 cubic feet. This mass, by no means a solid one, but interspersed and crossed in every possible direction by the trees, immediately checked the velocity of the stream and 10 days after it was commenced, the silt on its down-stream side had reduced the depth of the water from 16 feet to only 5 feet, equal to a silt deposit 11 feet in depth and extending down the river bank to a distance of about 8 times the length of the spur or between 800 and 900 feet. The work was continued to the full length of the spur and the roadway was made up to a level with the natural ground about 6 feet above water. This level was maintained and kept up by a small party of six men in renewing any portion of it where settlement occurred.

Rise in the river and its effects.—On the 24th January a rise of 1·7 feet in the river caused the top structure of this as well as all the other spurs to settle down very considerably, in places below the water level, these as before were quickly renewed. But the chief effects of the rise was a marked change at this part of the river after it had subsided to its normal level. The thread of the stream both above and below the spur had shunted off from the right bank nearly into mid-channel, and it seemed quite clear that the effect of the current off the end of the spur in the direction more or less of the spur itself had deepened the bed of the river and so prepared a deep stream to which the river subsequently took.

Changes in the river and how effected.—This I believe to be the only way in which the general direction of the river is affected. Spurs like these protect the bank for a very considerable distance depending very much on the shunt off they give the stream, the one No. III. caused the silt to deposit for more than a mile below it. But besides this protection, the direction of the stream is affected by the alterations which occur in its bed due to increased velocity at the end of the spur, and to scouring out. A succession of spurs therefore form a succession of channels or deep beds running out mid-streamwards, and when a freshet comes down, thereby increasing the velocity in the river, it cuts away as it were all the higher portions of silt between those channels, and so makes the mid-stream the deep bed of the river.

Point of impact of river.—About a fortnight after Spur No. III. had

been completed it was found that oscillations of the river had moved in an up-stream direction and that the end of the loop line *band* was being most violently attacked by the erosion. It was found necessary to start Spur No. 2*a*, this spur effectually checked the cutting for some time, but the set of the stream continuing upwards and cutting out a long deep bay above the loop line *band* eventually got round the heel of No. 2*a* Spur and formed a channel between it and the bank. By this time the effects of No. II. Spur had begun to act on the portion of the river between it and the loop line and the cutting action ceased about the end of January or three weeks after the spur had been commenced. It was not therefore necessary to keep up Spur No. 2*a* and it was allowed to go.

Spur No I.—In the meanwhile No. I. had been progressing. The impact of the river in the beginning of February following the same rule throughout, had again continued up-stream and its action was now most violently felt between Spurs Nos. I. and II., it was therefore considered necessary to check it for the safety of Spur No. II., and on the 17th February, No. 2*a*, a short Spur, was run out. The velocity at the time on the up-stream side of No. II. Spur had increased to nearly 9 feet per second, and erosion was going on with much force for a reach of 1,000 feet above it. Twice the spur was breached but fortunately with no permanent result, the breaches having been closed as rapidly as possible.

No. I. continued.—By the 1st March, No. I. Spur had attained a length of 300 feet and a few days later its full length of 400 feet, the last 100 feet having been built on the sand bank. Beyond the sand bank the water deepened rapidly, neither was it found necessary to prolong the work any more. Towards the middle of March the erosion, continuing as always, up-stream, set in without much violence opposite Spur No. I., and by the 2nd April when its length was measured it was only 207 feet. It was not found necessary to make it up again, as this could only have been done at great cost, and on its down-stream side the thread of the stream was directed off the bank, the additional length of spur was therefore not required for the protection of the others lower down. Subsequently the erosion ceased altogether, and on the 2nd April the spur measured 180 feet, this portion was kept up with a roadway on the top at level of natural surface.

No. 2a carried away.—But the erosion mentioned above had attacked the next Spur No. 2*a*, with so much force that it was finally carried away

on the 16th March. Before being finally washed down, it had been twice breached and twice repaired, and a large number of trees had been anchored out at its head in order to save it, but once the erosion ceased higher up at Spur No. I., and the force of the stream was off the bank it was not considered necessary to keep it up.

Spur No. II. attacked.—Spur No. II. which was originally 120 feet long lost 10 feet at its head by 1st March, on the 2nd 40 feet more had got completely submerged, but this was repaired and made up to its first level. Again the end of it sunk, and as the current also lessened very much here, it was not necessary to keep it up to the full length, the first 80 feet were strengthened and by the 2nd April, the velocity past the spur had very considerably decreased and no further apprehensions were entertained at this point.

Spur No. III.—Spur No. III. was partly carried away and a length of 110 feet was maintained and strengthened.

Changes in the direction of the river.—By the end of April, the main stream had left the right bank as far as the loop line *band*, Spurs Nos. I. and II. were lying almost in still water, No. III. had all the fighting to do as the impact of the river was on that part of its bank near the *band* from which it turned off sweeping past No. III. Spur with a very high velocity, and finally going off in an easterly direction.

Further changes.—By the 1st May the only part of the west bank, viz, the end of the loop line *band* was also abandoned by the river which took the straight course shown on *Plate* III., and made the result of the works undertaken during the previous 5 months a most complete success. The sites where the spurs were constructed are now a succession of large sand banks which have been raised to within 2 feet of the level of the adjoining ground by the silt deposit during the six months of May to October when the river was in flood. The floods having been much lower than usual this year the silt did not deposit to so great a height as it would have in ordinary seasons, that is up to the level of the ground.

Brownlow weeds.—The casks mentioned in the statement of cost of the works were used in making up the floating weeds known as Brownlow's weeds. These were anchored out in continuation of the spurs, but not in sufficient numbers to prove of much effect. I have worked with them before but never with satisfactory results, and before this could be attained in a river like the Indus it would require a very large number indeed of the

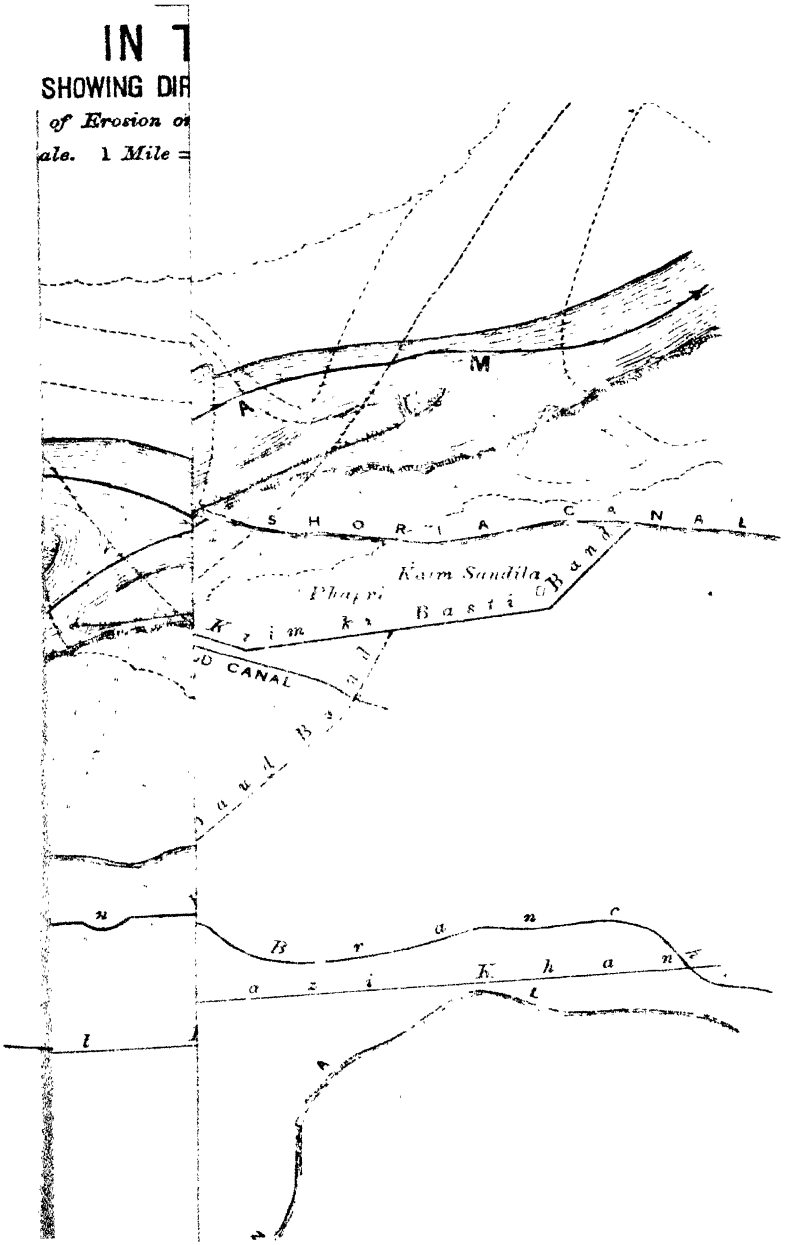
casks and weeds, in fact a regular forest of them if it was intended that by their checking the velocity of the water, a deposit of weeds, rubbish, silt, &c., should be formed, a small number of them is of no use, and as I did not use more than 20 at a time in the works at Kharakwalah, nothing was gained by them.

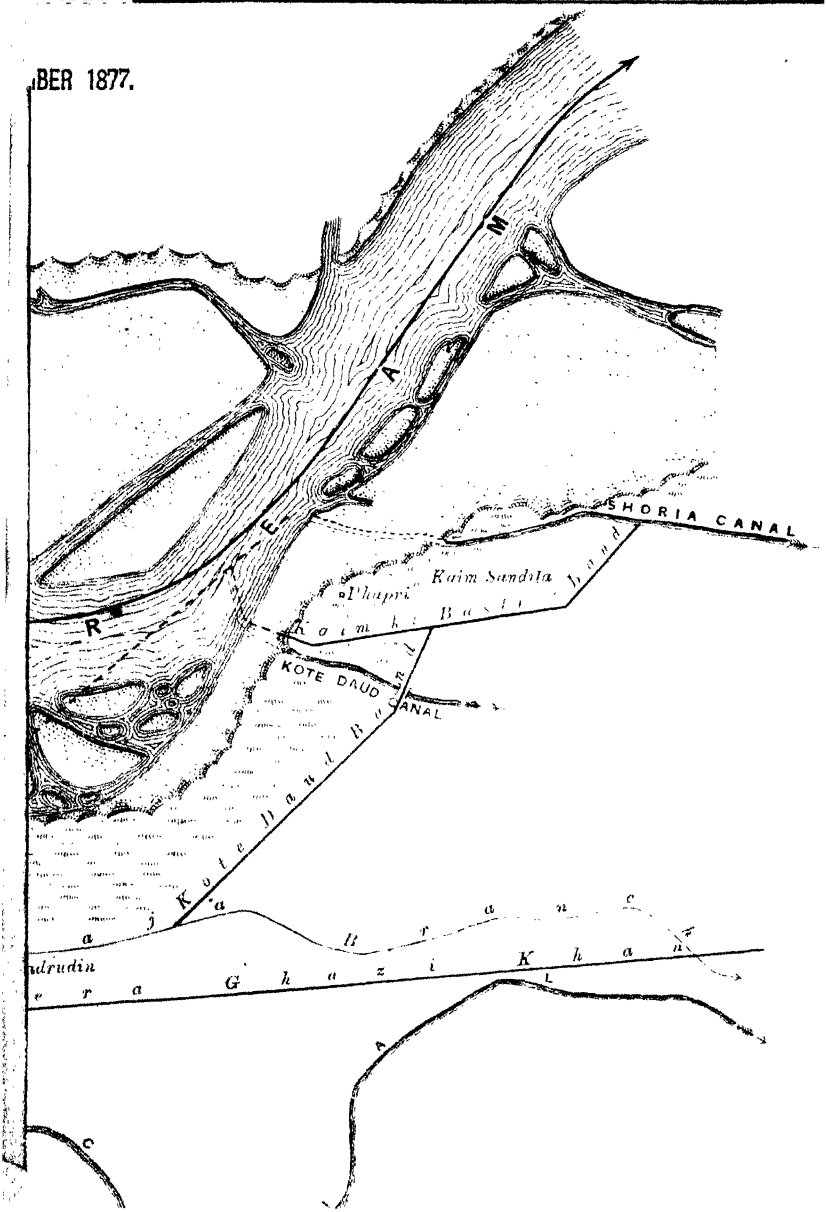
Cost of works.—A statement accompanies this report showing the cost of the works under the two heads of Spur No. I., and all the others in a lump. The cost includes all expenditure from the time they were commenced up to completion and forms a very fairly accurate estimate for other similar works under the same conditions, where the conditions differ rates of work can be deduced. From the statement we find that the cost per running foot of Spur No. I., was Rs. $6\frac{1}{4}$, other Spurs Rs. $25\frac{1}{3}$. Taking the cubical content of the two classes the first cost Rs. $3\frac{1}{2}$ to 4, the second Rs. 7 per hundred cubic feet. The labour cost about three-quarters, the materials about one-quarter, of the whole cost.

STATEMENT showing Cost of the River Defence Works at Kharakwalah, during the months of December 1876 to May 1877.

Items.	SPUR No. I.					SPURS, Nos. II. & III., & 1a. & 2a.		
	No.	RATE. @	RATE. Per	Amount.	Rate per r. ft.	No.	Amount.	Rate per r. ft.
LABOUR—Camels, ...	1,590	-/3/9	Day.	374	·0350	5,308	1,247	3·4639
Bullock, pairs, ...	1,470	-/8/-	"	735	1·8375	4,906	2,453	6·8139
Coolies, ...	2,409	-/3/3	"	488	1·2200	8,023	1,626	4·5167
Carpenters, ...	189	-/3/3	"	38	·0950	632	126	·3500
Mates, ...	219	-/5/6	"	76	·1900	738	253	·7028
"	276	-/3/3	"	56	·1400	924	187	·5194
Boat hire, ...	123	1/7/-	"	178	·4450	414	594	1·6500
Inspection boat crews for 6 months,	½	33/-/-	Month.	99	2475	1½	297	·8250
Total Labour, ...	..	..	..	2,044	5·1100	..	6,783	18·8417
MATERIALS—Cables, ...	1	43/-/-	Each.	43	·1075	4	180	·5000
Nets, large, ...	20	..	..	94	·2350	70	329	·9138
" medium, ...	23	..	..	50	·1250	84	150	·4167
" small, ...	2,009	..	..	150	·3750	8,100	510	1·4169
String and cord, ...	525	..	..	50	·1250	1,725	150	·4167
Sandbags, ...	114	..	..	40	·1000	386	135	·3750
Iron for repairs, ...	..	..	..	20	·0500	..	119	·3305
Casks, ...	10	..	..	25	·0625	202	504	1·4000
Compensation for trees, ..	..	..	..	..	..	..	255	·7083
Total Materials, ..	..	..	..	472	1·1803	..	2,332	6·4777
Grand Total, Labour and Materials,	..	..	..	2,516	6·2900	..	9,115	25·3104

T. E. I.


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BER 1877.
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Kote Daud Band
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Ghazi Khan
Gharra

No. CCLXXXI.

THE GOON CONCRETE BRIDGE, DALHOUSIE AND LUNSU ROAD.

[*Vide* Plate].

By Major T. C. Manderson, R.E., *Exec. Engineer, Dalhousie Division.*

This bridge was commenced in November 1876 and completed in September 1877.

The span is 66 feet and the rise of the arch (segmental) is 11 feet.

The width of the concrete arch is 15 feet 3 inches, thickness at crown 3 feet 8 inches, and on abutments 6 feet.

The width of the roadway inside parapet walls is 13 feet 3 inches.

On the right bank of the torrent, the abutment of the bridge, (composed of rubble masonry,) is founded on rock at a depth of about 16 feet below the springing level of the arch. The concrete arch rests on this abutment for a length of 16 feet.

On the left bank of the torrent, the concrete arch rests on solid rock for a length of 8 feet 6 inches.

The masonry of the right abutment of the bridge consists of roughly dressed stones of various descriptions, set in mortar, composed of equal parts of stone lime and pakka surkhi.

The superstructure masonry is of the same description of stones, set in mortar, composed of two parts lime, to one part of surkhi. The quoin stones of the masonry on right abutment, however, are of chisel-dressed blue sandstone.

The lime and surkhi were measured and mixed dry, and afterwards

ground together in native flour grinding mills, worked by water-power, about 50 yards above the site of the bridge.

In building, the stones for the masonry of the abutments, &c., after immersion in the torrent for several hours, were plastered over with mortar on all unexposed surfaces before being laid, and were rammed into their places with wooden rammers.

The left abutment was prepared by blasting and picking out a place of the required dimensions in the solid rock.

Whilst the right abutment was in course of construction and the preparation of the left abutment in progress, a centering composed of dry stone, carefully packed, was being built up across the bed of the torrent. The height of this centering ranged up to 28 feet.

In the bottom of this dry stone centering, three waterway channels were constructed, viz :—One 5 feet span, 11 feet high; and two 3 feet span, and 3 feet high.

The centre waterway of 5 feet span was covered over with a dry stone arch, and the smaller waterways with large stones.

The faces of the centre had a batter of 1 in 4.

The top of the dry stone centering was finished off with the same curve as the intrados of the concrete arch, which was to be rammed on top of it.

The width of the stone centre at top was made sufficient to allow of the construction of dry stone walls above it, with vertical inner faces, (and with a batter of 1 in 4 on the outsides) within which the concrete arch was to be constructed. A dry stone wall was also constructed at the end of the right abutment.

The inner faces of the walls built on the top of the centering and also of the wall at end of right abutment were plastered over with mortar, composed of one part lime to one and a half of surkhi, the object of the plaster work being to admit of the ready removal of the dry stone walls without injury to the faces of the arch, and also to allow of the curves of the layers of concrete being accurately marked on the surface of the plaster.

The top of the centering was concreted with coarse concrete, composed of one part mortar to five of ballast, laid on, of the necessary thickness, to produce the required curve of the intrados.

After this coarse concrete had been rammed and brought to a moderately smooth surface, small stones from the bed of the torrent were

sprinkled over it and rammed into it, the object of this being to facilitate the removal of the centering without injury to the under surface of the arch.

After this centering had been completed an unusually high flood, rising above the level of the top of the centre waterway channel caused extensive scouring under the walls, and it was found necessary to underpin them with dry stone, raise the floor of the waterway channel 4 feet as additional security, and form an extensive apron of stones thrown into the bed of the torrent on the down-stream side.

The construction of the concrete arch was next commenced.

The concrete was composed of one part mortar to four parts of ballast.

The mortar of the three lower layers of concrete consisted of three parts lime to two parts of surkhi, and for the upper ten layers, of two parts lime to one of surkhi.

The lime and surkhi were mixed dry, and afterwards ground together in native flour mills. The ballast was quartziferous rock, in size varying from coarse sand up to $2\frac{1}{2}$ inch pieces. This ballast was found in the bed of the torrent, about 400 yards below the bridge site. It was produced in the course of construction of the road, by the precipitation, from a great height of the rock blasted, from the hill side, into the bed of the torrent.

This class of ballast gave a low percentage of interstices, and the concrete could not be rammed down more than about 20 per cent.

The first layer of concrete was 6 inches thick on abutments and over arch, all the other layers were 4 inches thick at the crown and 7 inches on the abutments. To admit of these layers being accurately spread, curved lines were accurately drawn on the plaster on the inner faces of the walls on the top of the centering.

The ballast used at the crown of the arch was finer than that used towards the haunches. Roughly speaking the ballast at the crown did not contain larger than $1\frac{1}{4}$ inch pieces, whilst at the haunches they ranged up to $2\frac{1}{2}$ inches.

In all there were 13 layers rammed in this arch. The actual thickness of concrete laid on at crown was one 6-inch layer + twelve 4-inch layers = 54 inches, this was rammed down to 44 inches; on the abutment there was one 6-inch layer + twelve 7-inch layers = 90 inches, and this was rammed down to 72 inches.

From the crown to the abutments, therefore, the reduction due to the ramming increased from 18½ per cent. to 20 per cent.

The concrete was mixed in heaps of 4 cubic feet of ballast to 1 cubic feet of mortar paste, and it was mixed only as required. The ramming of the layers of concrete was effected with ordinary iron road metal rammers, and it was carried on until the consolidation was such, that no visible indentation was left on the surface of the concrete by a heavy blow, evenly dealt, with a rammer.

It took on an average three days to mix and ram a layer.

The spreading of the concrete and ramming were commenced from the crown of the arch and carried on to the haunches.

Mortar and mortar wash were used as required, to supply any deficiency of matrix or moisture.

Before spreading a layer of concrete, the side walls above the centering were "daubed over" with mortar to guard against any deficiency of matrix in those places where the ramming was most difficult.

The concrete arch was commenced on the 9th March and completed on the evening of the 4th May. The construction was much delayed by heavy and continuous rain-fall. Of the 57 days between the date of commencement and the date of completion of the arch, work had to be entirely suspended for 14 days. The actual time occupied in construction being 43 days and 11 nights.

On the morning of the 6th May, a flood which caused a heading up of the torrent to a height of 3 feet over the top of the concrete abutment, carried away a large portion of the centering. Again on the 9th May, another flood cleared out still more of the stone centering and the remainder was removed a short time afterwards. This sudden and unexpected removal of the centre caused no damage whatever to the concrete arch, and saved part of the cost of the removal of the centre.

The spandrel walls above the concrete arch were commenced on the 26th May, and the dry stone filling between them packed on in the month of August.

Selected stones from the remains of the centering were used in the construction of the spandrel walls, dry stone backing of the arch, &c.

For dimensions, *see Plate* attached.

The Bridge is intended to bear cart traffic, and cost Rs. 6,722.

T. C. M.

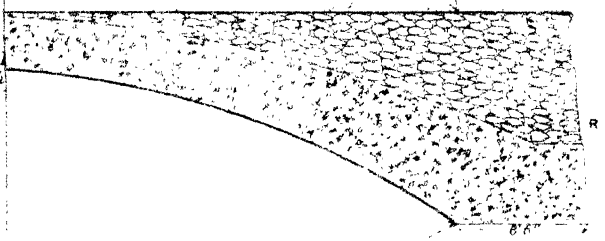
E DALHC

inch = 10 feet.

TION

Level

Level of Water
on May, 6th



ROCK

o u l d e r s

NICE

foot



No. CCLXXXII.

NOTE ON DIFFICULTIES IN CONSTRUCTION OF A TUNNEL, HOLKAR RAILWAY.

By the Engineer-in-Chief, Holkar and Neemuch Railway.

TUNNEL No. 2 of the Holkar State Railway is situated on the 67¼ mile from Khundwa on the 1 in 40 incline. The length of the tunnel is 115* yards, all of which is lined.

The character of the formation through which Tunnel No. 2 passes is very peculiar, consisting of what appears on the outside to be fairly columnar basalt, the columns of which are very high, in some cases as much as 40 or 50 feet, but are so irregular, that they may more properly be described as a series of cones, some held together by the clay in the joints, while others are retained in their position by pressure.

In running the heading, the material met with showed no tendency to slip, attributable no doubt to the dimensions of the heading, these being only about 6 × 6 feet in section. Throughout its length blasting was necessary.

No difficulty in working out the full section of the tunnel was therefore apprehended, and the complications and difficulties which have since been experienced only became apparent when the open cuttings at each end were completed; the material then appeared sound enough to tunnel.

Tunnelling operations were commenced on the full section in June 1876, but on the 3rd July 1876, at 3 A. M., when the work was being pushed on day and night with both ends shored up to avoid risk, both faces slipped almost simultaneously; such a coincidence could hardly be expected to occur, but it was no doubt caused by the heavy rain which fell on the 1st July, and this percolating through the joints, caused masses of de-

basalt to slide. By this accident 14 men were shut up inside

the tunnel for about 9 hours, when a small drift was made through the *débris* sufficient to allow of the 14 men being drawn out, happily with no worse result than that of having been shut up under ground for 9 hours in a confined space.

It became necessary to shore up both the faces exposed by these slips in a very substantial manner, and the east face presenting the worst features was shored up from top to bottom, to a height of about 60 feet, with baulks of teak 14 inches square in section, the uprights and raking struts being all firmly wedged up against the face of the tunnel.

In August 1876, when everything was again ready for a fresh start and all the *débris* had been removed, another vertical slip, carrying all stagings with it, occurred, and the work was stopped. A third time shoring was put up, and material delivered at site to enable the lining to be carried on, but just as the centre line was being staked out to allow the masonry to be started, another slip at each end occurred and stopped progress. The cause of the slips was that the clay fissures becoming wet, allowed the blocks of murum to slide; these blocks were all in the shape of cones, and a disturbance of one was generally followed by the fall of a very large mass.

It was not till the commencement of the cold season of 1876-77 that the shorings were completed, when it was thought that with dry weather the difficulties or delays caused by slips would cease; the *débris* were cleared out, and the sides widened to full section, portions that exhibited a tendency to slide were all shored up; horizontal timbers resting upon uprights were advanced inside the tunnel, and a length of about 50 feet of lining outside the east face of the tunnel having been finished, a fresh length of 12 feet was started, and the side walls of this made ready for centres and for arching.

On the 4th December 1876, when the centres were being put up close to the mouth or face of the tunnel, the whole of the face from top to bottom of cutting slipped, carrying with it all the timbers and smashing most of them to pieces, and shutting up inside the tunnel heading 10 of the men who were engaged on their erection. The west end had been closed by a slip some time previously, and the *débris* had not then been cleared away. The hope of relieving the men from the east end was so discouraging, that no attempt to get in from this end was made, as the quantity of material to be removed, and the large quantity of timber known to be

in the shorings would have interfered with progress and prevented access to the heading for several days. Every effort was accordingly made to communicate with the men from the west end, and a gallery was pushed in for a short distance, when part of the broken timber staging stopped the progress. At the same time the upper portions of the cliff gave indications of a fresh slip. Attempts were made to pull down some of the top pieces of rock by means of tackle worked from below, but little progress was made, for as fast as the *débris* were removed, more of the face fell in. By removing the *débris* as fast as the gangs could work, a small hole leading into the heading was struck, and communication was made with the men inside, who were then with the greatest care drawn through the aperture all safe after having been shut up in the heading for about 30 hours. This accident, irrespective of the difficulty experienced in relieving the men, and the disappointment of the work being again delayed, was the worst one that had occurred.

As a result of these slips, the *débris* had to be carried away through the portion of the entrances already lined, and with broken timbers and centres all jumbled together in a working face of 16 feet, progress was delayed, while the face became worse by time. An endeavour was made to advance the work on both sides by 6 feet lengths, so as to carry on the lining *pari passu* with the widening and clearance of the entrance, but this failed from the faces becoming too dangerous for the men to work beneath.

As the early opening of the through line to Mhow depended upon the completion of this tunnel, a special Committee was assembled on the 1st February 1877, to devise measures for the prevention of further mishaps, and for the safe and rapid prosecution of the works, so as to endeavour to have the tunnel in a state which would admit of trains working through it with safety during the monsoon of 1877.

After careful consideration of the importance of opening the Ghât section within a reasonable period of time, and bearing in mind the means which have been adopted in the construction of tunnels on other railways, the Committee recommended that an open cutting should be made through the spur, arching put in, and murum filled in over the arching to act as a cushion.

On receipt of the Report of the Committee, the Government of India approved of the substitution of an open cutting, and arching over the line

of railway for the originally proposed tunnel, but at the same time suggested that the prudence of turning heavy arches over the approaches to the tunnel should be considered, as if slips were rendered harmless by the adoption of this measure in front of the faces of the tunnel, it might be possible to proceed with the closed cutting, and with greater safety than the proposed open one.

It was, however, found that no advantage would be gained by turning heavy arches over the approaches to the tunnel, as when the excavation forward and down from the surface proceeded, there appeared no change in the nature of the material which rendered it so liable to slip on the faces, and it was not likely that harder material would be met with, and that consequently tunnelling operations could not be renewed; the result has justified the opinion.

By the end of April 1877 about 60 feet in depth of cutting had been done, and preparation made to line about 50 feet of west approach. The work was vigorously pushed on to a depth of about 100 feet, when the following slip stopped its progress for some time.

On the 14th September 1877 the central portion of the upper or northern slope of the cutting at about 75 feet from the top bulged out for a distance of about 100 feet and fell in, completely filling up the portion excavated to a height of about 75 feet above the formation level. The excavation previous to the slip had been almost completed to a level of about 15 or 18 feet above formation, and a length of lining of 12 feet had just been completed, and before this latter could be covered over with filling, a large portion of detached rock struck it, and broke part of it. The centres had not been removed and two of these were smashed. About 30,000 cubic feet of stuff fell in, but fortunately no one was at the time in the cutting, or escape would have been almost impossible. It took nearly six weeks to clear the *débris* of this slip.

Since this date no serious accident occurred and the progress was uninterrupted, and on the 20th December 1877 the tunnel was made ready for the necessary inspection before opening.

CCLXXXIII.

LIMES AND CEMENTS.

By P. Dejoux, Esq., *Exec. Engineer, Cements Division.*

To the Editor Professional Papers.

Calcutta, 18th May 1878.

Dear Sir,—I have the pleasure of sending you a printed copy of a Paper on Limes, Cements, &c., I have just sent to Government for circulation, thinking you should like perhaps to reproduce it in one of the Numbers of the Professional Papers on Indian Engineering.

I will also send you in a short time a rather long paper on Manufacture of Portland Cement in India with any kind of limestone, including kankar, &c.

2. I need add that while Part I. of the paper is, more or less, based on theory, Part II. contains practical remarks concluded from experience as well as theory.

P. D.

Part I.—PAPER ON LIMES, CEMENTS, SANDS, SURKHI AND MORTARS.

1st.—Induration of fat lime.

1. If pure lime is dissolved in water and left exposed to air, the carbonic acid combines very speedily with the lime, and the carbonate of lime formed gets precipitated as pellicles, which adhere strongly to the solid bodies coming in contact with them.

2. If the lime instead of being dissolved in water is left exposed to air and gets dry quickly, it absorbs the carbonic acid, but the grains of carbonate remain separated without adhering to each other.

2nd.—Induration of a mortar of fat lime and sand.

1. If such mortar is immersed, or kept in a place always damp, the lime after a time dissolves entirely and sand alone remains.

2. If the mortar is allowed to dry quickly, the lime rapidly absorbs the carbonic acid, and the result remains in a mixture of sand and calcareous powder not adhering together.

3. If otherwise the mortar is kept in a proper state of moisture, the lime dissolving slowly will absorb the carbonic acid.

The carbonate will not be washed away, but on the contrary get deposited as a kind of varnish on the grains of sand.

The water then in presence of the excess of lime remaining will dissolve another small quantity of it, which, being transformed also into a carbonate, will adhere to the first coating strongly. The process will continue in the same manner until the entire induration of the mass of mortar.

3rd.—Effect of sand on mortars.

1. The effect of sand is purely mechanical, and no chemical composition between the sand and lime takes place.

2. It facilitates the passage of the carbonic acid through the mass.

3. If it has sharp angles, it gives a good hold to the carbonate formed by exposure to air, and increases the degree of cohesion of the mortar.

4. The strength of a mortar of fat lime increases proportionally from $\frac{1}{2}$ to 2 parts of sand for 1 of lime.

5. The sand must be coarse and sharp. In fact, the size of the grain of such sand ought to vary from $\frac{1}{100}$ to $\frac{6}{100}$ of an inch.

4th.—Surkhi as a substitute for sand.

1. In places where good sand is not obtainable, the best substitute for it is "surkhi," the powder of well burnt bricks. Indeed, the harder the bricks are the better will the surkhi be.

2. It will then act similarly to sand as an inert matter, not giving any hydraulicity to the mortar.

3. The size of the grains of such surkhi ought to vary from $\frac{1}{100}$ to $\frac{6}{100}$ of an inch.

5th.—Induration of hydraulic lime.

1. An ordinary hydraulic limestone contains silica, alumina, carbonate of lime, and small proportions of oxide of iron, magnesia, manganese

and sulphate of lime, which generally cannot have an appreciable effect on the setting of the lime.

2. When calcined, silicates and aluminates of lime are formed and some hydrated lime remains with the other foreign matters. Upon being made into paste by the addition of water, the silicates and aluminates of lime get hydrated and crystallize afterwards, and therefore harden. Some of the hydrated lime gets transformed into carbonate of lime, and some dissolves in proportions varying according to the quantity of silica and alumina contained in the lime, forming either smaller or larger proportions of silicates and aluminates of lime.

6th.—Induration of hydraulic mortars made with fat lime and properly burnt clay or puzzolanna.

1. If a fat lime is mixed with a certain proportion of pure clay burnt to the proper degree, the same reaction as for hydraulic lime takes place in the setting of the mortar, with the difference that, if enough powder of burnt clay is mixed with the fat lime, almost the whole will be transformed into silicates and aluminates of lime, provided it is either immersed or kept in a place always damp.

2. A mortar of first rate puzzolanna and a suitable proportion of lime will therefore have very little lime dissolved, and will be less porous than a mortar made with hydraulic lime and sand.

3. It may be said, however, that, on account of the great difficulty of burning clay or puzzolanna to the exact degree required for the maximum power of combining chemically with the lime, a good hydraulic lime is preferable on the whole.

4. The proportions in which surkhi ought to be used for different sorts of lime will be found in Part II.

7th.—Remarks on surkhi made of burnt clay or of common bricks.

1. As it has been stated in Chapter 6 that half burnt clay combines chemically with fat lime, it is necessary to explain now why the clay must be so burnt.

2. Let us, however, first define pure clay.

Pure clay.—It is a clay which should be free from sand and carbonate of lime, or, if it does contain both, it should not be more than 5 per cent.

Clays are hydrated combinations of silica and alumina.

The degrees of calcination which give them the maximum of hydraulic properties have been found, by experience, to be the same as the degree of calcination required for expelling entirely the water contained in the clay. Therefore to transform clay into a kind of puzzolanna, the theoretical calcination must be regulated so as to expel the last particle of water without exceeding 1100° to 1300° Fahrenheit. This is what Vicat calls "cuisson normale" (normal burning).

3. *Impure clays containing sand, carbonate of lime, &c., and brick-earth.*—A calcination lasting a longer time than for pure clay, to a temperature varying from 1300° to 1500° Fahrenheit, is required for expelling the carbonic acid, &c., from such clays. The fact of requiring a higher temperature is the cause of the inferiority of the surkhi made with common bricks.

4. From the above it is to be considered that surkhi made with pure clay or common brick-earth requires only a slight calcination.

5. However, the practical hints for burning clay to the proper degree will be found in Part II.

8th.—Induration of cements, either natural or artificial.

1. Cements set quicker than any hydraulic lime, and their hardening increases much more rapidly.

2. This is due to the fact that in cements very nearly the whole of the clay and lime is transformed into silicate and aluminate of lime, either on account of the large proportion of clay contained in cements of the quality of Roman cement, or on account of the high temperature to which cements like Portland are burnt.

The silicates and aluminates get hydrated very quickly, and then crystallize in a very short time, in comparison with hydraulic limes, which always contain an excess of lime not combined.

9th.—Lime-cements.

1. A great many kankars or ghooting stones in India can be considered as containing a mixture of hydraulic lime-cement, more or less quick-setting, and a certain quantity of free sand and clay, which act when burnt as inert matters.

2. The kankars generally slake very little, and require always to be ground fine either before or after slaking.

3. These kinds of lime-cements ought to be used only with sand or

extra burnt surkhi, but the admixture of half burnt surkhi would be very prejudicial to the strength of mortar after a certain time.

10th.—Hydraulic limes or cements containing sulphate of lime.

1. According to Vicat, Rivot, and other authors of treatises on limes, any hydraulic lime or cement containing a rather large proportion of sulphate of lime cannot be considered of good quality.

2. Rivot mentions that, from the experiments made up to 1876, it has been impossible to fix exactly what is the largest proportion of sulphate of lime which can exist in a lime without injuring its hydraulic properties and the stability of the mortar immersed.

3. Vicat says that any limestone not containing more than 2 per cent. of sulphate of lime can be very safely used for any hydraulic work.

4. It is easy to understand the reaction which takes place with the sulphate of lime contained in an hydraulic lime. The sulphate when strongly calcined gets hydrated very slowly, and its crystallization takes place after the setting of the mortar. The increase of volume may therefore disturb the mass of the mortar, especially if it has been immersed immediately after being prepared.

5. I should say, however, from personal experience, that for mortars made with hydraulic limes not containing more than 10 per cent. of sulphate, which have been allowed to set slowly for a certain time in air, and then put in contact with water, the stability will not be disturbed. The only effect will be its becoming more porous when the sulphate of lime gets slowly dissolved in water.

PART II.—PRACTICAL REMARKS.

1st.—Mortar of fat lime and sand.

1. Such mortar ought to be used only for buildings not exposed to great dampness.

2. If the lime is very rich the best proportion should be:—

2 parts of sand, and
1 part of lime.

3. If the lime is meagre (containing notable proportions of clay, sand and magnesia) the quantity of sand must be reduced proportionally.

2nd.—Mortar of fat lime and surkhi (half burnt).

1. *Works immersed.*—For works constantly under water half burnt surkhi only must be used, and the following proportion is the best for a rich fat lime :—

2 part of fine (half burnt) surkhi, and
1 part of lime.

2. *Works exposed to the inclemency of the weather.*—For buildings exposed to heavy rain and the damp climate of Bengal, as also to the heat of the sun, it will be advisable to use a portion only of half burnt surkhi and a portion of sharp coarse sand, or coarse surkhi extra burnt; but the proportion which seems the best for a rich fat lime is :—

1 part of fine (half burnt) surkhi ;
1 part of coarse (extra burnt) ditto ; and
1 part of lime.

3rd.—Mode of preparation of surkhi possessing hydraulic properties.

1. *Surkhi made with pure clay.*—For works in which a very hydraulic mortar is required, it is preferable to make surkhi from pure clay cut in small pieces of about the size of an egg (as found in its natural state), and then burnt either in clamps or in a kiln. When lime kilns are at work at the same place where the surkhi is manufactured, the best way to burn it to a proper degree is to load the top part of the kiln with the raw clay and the bottom with limestone. The hydraulic surkhi called half burnt above, may be considered to be burnt to the proper degree when it has been submitted to a *red dark heat* and cannot dissolve in water; it must, in fact, be a kind of very soft brick which will, after a certain time, be affected by exposure to air, but which must have lost the plastic power of raw clay when mixed with water.

Surkhi made with common brick-earth.—This surkhi must be burnt for a longer time until the carbonate of lime it contains is calcined, however the burnt bricks must be only a little harder than those made with pure clay.

Sifting.—These two surkhis made either with pure clay or common bricks require to be ground so fine as to give the fat lime all their hydraulic properties. They ought to be sifted through a sieve of 40 meshes to the lineal inch.

The chemical combination between the lime and the burnt clay cannot

take place if the powder is coarse, and the mortar will be injured by the introduction of a soft inert body.

4th.—Mode of preparation of surkhi as a substitute for sand.

1. *Burning.*—The surkhi which is to be used either with fat or hydraulic lime and cements when sand is not obtainable, acting then as an inert matter, must be made either with clay or bricks perfectly well burnt, very hard, and in fact a little vitrified, if possible.

2. *Grinding and sifting.*—This surkhi must not be ground fine; and the grains ought to be of such a size as to pass through a sieve of 8 meshes, and not pass through one of 16.

5.—*Remarks on the mode of treating various kinds of hydraulic limestones, kankars or ghootings.*

1. Every hydraulic limestone, kankar or ghooting, containing less than 25 per cent. of either clay or sand, should be burnt, slaked, sifted, and the refuse rejected. If the lime is properly burnt, the refuse of it ought not to be much.

If the refuse, however, is ground and mixed with the lime, it may impart to it portions of a kind of cement, but it also generally contains a good deal of inert matter, and thus the lime will bear a less proportion of sand than if only the slaked lime was used, and hence no savings in the final cost of the mortar will be effected by such a process.

This rule is applicable to the generality of ghooting stones found in Lower Bengal.

2. Now supposing that the kankar or ghooting lime contains more than 25 and less than 33 per cent. of clay and sand, and that the proportion of free sand (not in the state of impalpable powder) exceeds 5 per cent., it will be better to act with it as above shown; but if the stone is rather free of sand, the lime may be slaked when burnt, and the whole pulverized by a surkhi-mill before screening.

Such lime will in every case bear less sand than that described above.

3. If the kankar contains more than 33 per cent. of clay and sand, the last process will be found more advantageous than ordinary slaking.

Some of these burnt limes do not slake when water is poured over them. For these however it is evident that grinding is necessary; but there are others which seem to slake, or at any rate, turn into coarse powder.

In many cases apparent slaking results only from partial disintegration of the mass. The parts containing enough clay to become a kind of cement are then in too coarse a state to have any binding properties, and very often sand is the principal constituent of the finer portion.

Such lime may be considered as composed of a mixture of sand, hydraulic lime in very small porportion, cement of very variable quality and some kind of puzzolanna; consequently a very satisfactory result can only be obtained by grinding the whole of the burnt stone.

However the powder thus obtained will never bear a large proportion of sand in the mortar.

It may even happen that the lime must be used alone as mortar, without any admixture, when the chemical composition of the stone shows that it already contains a large proportion of free sand.

This kind of kankar is very common in the Punjab and the North-Western Provinces.

Remarks about sifting.—All these limes and lime-cements ought to be sifted through a sieve not coarser than 20 meshes to the lineal inch; but when very quick setting is required, a sieve of 40 meshes ought to be used.

It may seem strange to use for fine half burnt surkhi a sieve of 40 meshes and for lime one of 20 only. The reason is, that lime tolerably burnt could if properly dried pass through a sieve of 40 meshes quite as well as one of 20, by leaving very little residue; but as the particles of fine lime adhere always, more or less, together, the sieve of 20 meshes is quite sufficient, but it will not answer for surkhi which is made with very dry bricks.

6th.—Use of surkhi and sand with hydraulic lime.

1. *Limes very hydraulic.*—All the hydraulic limes which slake well, and set under water in less than five days can be safely used without the addition of fine half burnt surkhi for any hydraulic works.

They ought to be used with either sharp sand or coarse surkhi (extra burnt).

2. *Limes moderately hydraulic.*—Limes taking more than five and less than ten days to set under water do not require any admixture of half burnt surkhi for works not requiring a great degree of hydraulicity.

For works immersed and requiring to be very hydraulic, the following proportions can be used:—

1 or 1½ parts of sand or coarse extra burnt surkhi ;
½ part of sand or half burnt fine surkhi ; and
1 part of lime.

3. *Limes feebly hydraulic.*—They can be considered as impure fat lime, and treated in the same way.

4. *Lime-cements.*—Such lime-cements as slake very little and require grinding, do not as a rule, require admixture with half burnt surkhi.

In fact they give better results when simply mixed with either sand or extra burnt surkhi and the proportion for these cements ought never to exceed—

1½ parts of sand or extra burnt surkhi, and
1 part of lime.

7th.—Cement-mortars.

1. *Quick setting cement.*—For a quick setting cement of the kind of Roman cement, the proportion of sand ought not to exceed—

1 part of sand, and
1 part of cement.

2. *Slow setting cement.*—For Portland and magnesian cement the best proportion is—

2 parts of sand, and
1 part of cement.

For Portland cement, the quantity of sand could be increased very much with careful workmen, but with native masons it will not be safe to exceed—

4 parts of sand, and
1 part of cement.

3. *Remarks.*—Cement must always be used with less water than hydraulic lime, and hydraulic lime with less water than fat lime.

4. *Substitute for sand.*—If sand is not obtainable, extra burnt coarse surkhi can be used instead ; but the strength of such mortar will be always below that of sand mortar.

No. CCLXXXIV.

TEAK AND MASONRY HOUSES, BURMAH.

[*Vide* Plate].

By Robert King, Esq., *Exec. Engineer, Rangoon Town Division.*

Rangoon, 7th January, 1878.

Two similar buildings, one for the Superintendent of Wharves, and one for the Strand Preventive Officer, have been built on the river bank, Rangoon, one on either side of the Soolay Pagoda Wharf. Each building is surrounded by a rail enclosure, neatly planted.

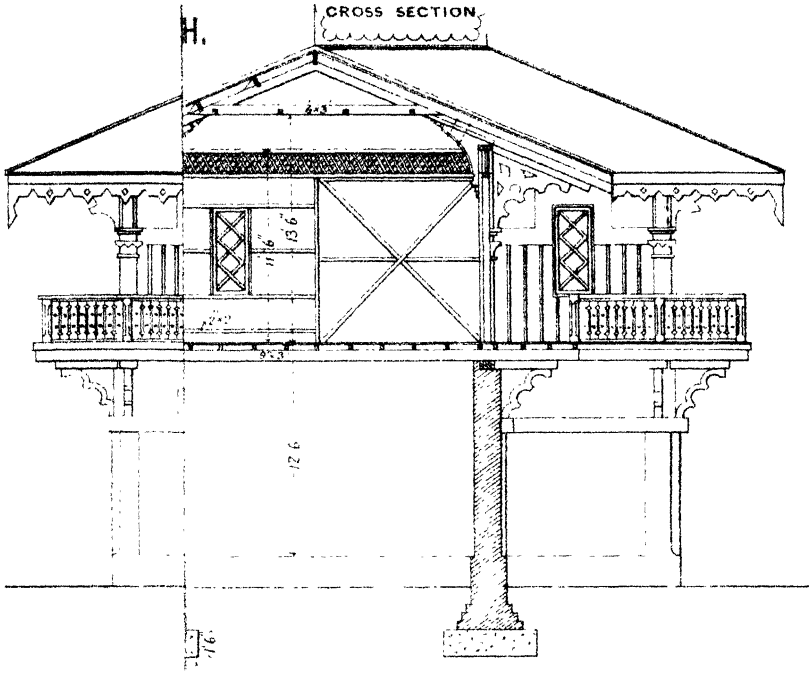
The basement floor consists of a dining-room 16′ 6″ × 16′ 6″, an office 16′ 6″ × 16′ 6″, and a porch 16′ 6″ × 7′ 6″, the walls of this floor are built of good bazaar bricks in mortar, the outside plaster being cement, and the inside lime. The floor, which is two feet above the ground level, is ¾-inch of asphalte over 6 inches of broken brick concrete. The first floor is entirely of teak, covered with a corrugated iron roof, the posts supporting this roof, and to which the wall framing is secured, are morticed into a frame resting on and bolted down into the basement walls. The floor is of 1 inch teak, grooved and tongued. The verandah floor overhangs the basement and is supported from the pillasters of the basement, by handsome carved teak brackets.

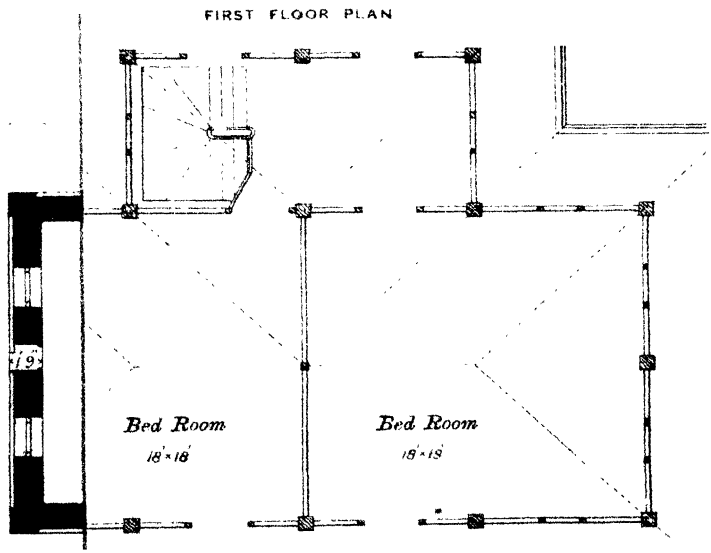
The walling of this floor is of ½-inch teak planking grooved and tongued, the vertical joints being covered by 1½″ × ¾″ splims with chamfered edges, a string course 9″ × 1″ runs horizontally around the building and lintels of the doors, the walling begins 6 inches above this floor, and terminates 1 foot 5 inches below the underside of the wall-plates, the space under the wall-plates being filled up with jaffery work, and that immediately

above the floor with a 6″ × 1″ ledge board hung on hinges. All rooms and verandahs on this floor are ceiled with half-inch planking grooved and tongued and painted white, the doors on basement are all panelled, on the first floor one-third panelled and two-thirds venetian. The windows are $1\frac{1}{2}$″ glazed parisian sashes with diamond-shaped panes. The hand-rails to verandah are cut out of 5″ × 3″ and filled up with $\frac{3}{4}$-inch perforated teak boarding with $1\frac{1}{2}$-inch teak moulding at top and bottom. The crest on the ridge and the eave boards are cut out of 1 inch planking and painted slate colour. All exposed timbers are earth oiled.

The above is about the smallest of the many buildings of this description designed and built by Mr. Mathews. The General Hospital, a very large and commodious building, was completed in March 1872; this building is entirely of timber with a shingle roof: the High School has a brickwork basement and timber first floor and shingle roof, the clock tower is of timber above the basement: the Sailors' Home is a very handsome building with brickwork basement, teak first floor and Mangalore tiled roof.

R. K.


H.
CROSS SECTION
13'6"
11'6"
12'6"
16'


FIRST FLOOR PLAN
19'
Bed Room
18'×18'
Bed Room
18'×18'

No. CCLXXXV.

THE DUTIES OF THE PUBLIC WORKS DEPARTMENT DURING TIMES OF FAMINE.

By Major C. C. Scott-Moncrieff, R.E., C.S.I., *Famine Commissioner and Offg. Chief Engineer, Mysore.*

The Viceroy last year ruled that the Public Works Department should henceforth be the Chief Agency for Famine Relief in India, and that the best and most economic form of all relief was the construction of large and well devised works under Professional Agency.

We have good cause to thank His Excellency for assigning to us so honourable a rôle. He has elsewhere likened a famine to a campaign, and those who have gone through both will appreciate the likeness. Wars are happily rare now in India—not so famines. Many of us came out to India thinking our highest achievement was to be found in the construction of a great bridge, or the opening of a canal or of a railway. Now we have a still higher career open to us to serve in the foremost rank in the very forlorn hope, in saving thousands from death. Nor is it so very easy. The Engineer that successfully controls famine labour must think little of himself, every thing of his work. For him are no holidays, no sport, no society. Patience, temper, firmness and kindness, must always be exercised. He must endure constant exposure to the sun, weary monotony of work, many bad smells, many sad sights. He must eat his meals and write up his accounts when and where he can. He must not be above attending to many new duties. He must look closely after the camp water supply. He must see that the bazaar is well

supplied. He must himself superintend the feeding of small babes and sickly mothers. He must attend closely to conservancy. He must see that his hospital is clean and well supplied with necessaries and that the medical subordinate is doing his duty, that loathsome ulcers are being dressed, that itch ointment is being applied, that guinea worm cases are being attended to, that the weakly are getting suitable diet, that the dead are being buried deep, and when, as is likely enough, cholera visits the works, the Engineer must know how best to meet it and must keep a cool head. And the reward for all this labour? He will be the means of saving many lives. That is surely enough?

I do not suppose for a moment that all Engineers will appreciate famine relief work. There are some I fear who could never warm into interest sufficient to care to take all this toil to save the life of our dark-skinned brother more unsightly than ever when stricken with famine, dirty and haggard, and offensive.

There are other Engineers pure and simple who look on all this as a most aggravating interruption to their regular work. I do not find fault with them. Only the honour of famine relief cannot be theirs. They can have no heart for this campaign, nor ought they to reap its laurels.

As no good soldier would wish for war only that he himself might reap honour, so would no good Engineer wish for a famine. But the good soldier prepares himself beforehand. So should the Engineer, and in the following Note I propose to record a few points which may be useful, not evolved from my inner consciousness but from the experience of the last year. I would treat of,

I. The duty of the Local Government and its Chief Engineer in preparing projects for Famine Relief.

II. The style of work best suited for the purpose.

III. The comparative merits of a few large works, and many small ones.

IV. The action of the P. W. Department when the approach of a Famine is dreaded.

V. The scope of its duties in a Famine.

VI. The management of a Famine Relief Division.

VII. The close of a Famine.

I. It behoves the Chief Engineer of every Province to have in his office a set of projects all cut and dry suitable for famine relief work. By consulting officers of local experience such projects will not be hard

to find. Most Collectors and Deputy Commissioners have got some pet scheme they would like carried out if they could only get the money, some road to be made, some swamp to be drained. Public Works officers are always on the look out for such works, and it will be a long time before the list is exhausted. There are many regularly taken up by Government, surveyed, designed estimated but laid aside for financial reasons. And there are slack times when the Chief Engineer has one or two officers on his hands more than he actually requires. What better can they be doing than in working up projects for the Famine Relief drawer ? The history of the last famine has been most instructive on this head. A few years ago Bombay had an Irrigation Chief Engineer enthusiastically interested in his work, who had project after project drawn up for irrigating the Dekkan by canals and tanks.

One after another was refused as not being financially profitable, and when Colonel Fife went home he may have looked sadly at all the labour bestowed on these schemes, and to all appearance wasted. The famine set in. There was a cry for Relief works, and Bombay has come out of its troubles with Colonel Fife's tanks and canals approaching completion. Very likely they will never pay 5 per cent. on the cost of their construction, but when a people have to be kept alive anyhow by the State it is something to get in return a set of works affording the best safeguard against another Famine.

II.—The best style of relief work, is that on which can be employed to the best advantage for a considerable period of time large numbers of unskilled workers—men, women, and children. And that employment is unquestionably earthwork, which possesses the further advantage of requiring no outlay in costly materials, such as bricks, stone, iron, lime, &c. It is of great importance to have this labour as concentrated as possible, for it must be clearly understood that the object of a relief work is primarily the welfare of the workman. The feebler the workman the more is the necessity for looking after him, and this at once prevents the employment of contractors, and makes that work unsuitable which cannot be daily inspected by an intelligent and trustworthy officer.

Viewed in this light, road-making is good relief work in proportion as the country is hilly without being rocky, and the construction of a railroad is far superior to that of an ordinary road. In the great plains of Northern India, neither a road nor a railroad can be con-

sidered as the best style of relief work. For just think of what they involve. A mile of road 50 feet wide, raised three feet high across a level plain will be finished by perhaps 1,000 coolies in a month, and if relief works are kept open for six months these 1,000 coolies will have made six miles of road. Now, supposing there to be no other work in progress within six miles on either side, this road will have to provide employment for 72 square miles, and if the population is 300 per square mile it will occupy less than 5 per cent. of them, a small proportion in a famine stricken country.

Moreover one Sub-Divisional officer ought to be able to look after 4,000 coolies, and if 4,000 are concentrated on this road the six miles will be finished in six weeks, and officer and labourers must all be moved elsewhere, which is inconvenient. A canal, a canal escape, or a deep drain are all more suitable works. Drains have one advantage, that from their nature they must be made in low lands. These are often swamped in other years, but in famine years when the country is parched it is just the time to dig them out. Any irrigation officer in Northern India will testify to the value of canal escapes and regret that there are so few. Digging new escapes is an excellent form of labour, for it is almost certain to infer heavy earth work within the space of a few miles.

Where the country is more broken it is easier to employ thousands of labourers within a limited space. Nothing can be better than the *band* of an irrigation tank. Some of the great Dekkan *bands* of the Bombay Presidency made last year were large enough to employ 20,000 coolies for six months and more: and that all within the space of three miles.

A railway through broken country is nearly equally good employment, and one now being made in Mysore gave continuous occupation to about 13,000 coolies for the period of nine months, although only about 20 miles was accomplished.

Road repairs are, for the reasons stated above, a bad form of relief labour. It is impossible to employ very many in one place. A number of small parties infers a number of subordinates in charge.

The subordinates cannot always be selected carefully. Temporary hands must be employed, and the certain result is that the work is not properly supervised. Either exclusive attention is paid to the cooly, regardless of the work, or to the work regardless of the cooly. Happy the Executive Engineer, whose temporary overseer does not neglect both.

Road metalling moreover is not quite so easily tested as plain earthwork, and there is more skill in performing it; but in a great famine we cannot be choosers, and this must often be taken in hand, for want of something more suitable.

The collection of road metal or railway ballast is better than road repairs and affords good occupation especially to women and children, while if the metal be of a kind that will not deteriorate with time, a substantial return is obtained for the outlay.

The opening out of endless new roads between places where they are not wanted, should be steadily discouraged.

Probably there is not a district that has been visited with famine in the last few years, that cannot show miles of these futile works. If they are ever finished the district funds cannot keep them in repair. If as is more likely they are left unfinished, the good land they occupy is thrown out of cultivation.

The reader may say :—"All this kind of work is for the unskilled. Is the skilled artisan to be allowed to starve?"

The Famine Commission now sitting will doubtless fully consider this point. Hitherto Government have only proposed to save life, not to protect from poverty. It is hard to see how State aid could be given to help some artisans in their own craft, such as jewellers, goldsmiths, ivory workers, &c. The ordinary weaver might be easier employed at a state loom, but that would be outside of the Public Works Department.

We could find work, each in his own line, for the mason, the carpenter, the bricklayer and the blacksmith, but it would entail great expenditure, and close supervision. If State aid be given in building bridges, barracks, &c., for every thousand rupees spent on actual famine relief, at least three thousand will be spent on materials.

It has been said that one Sub-Divisional officer can look after 4,000 coolies digging. It would be difficult for him to superintend buildings employing half this number, earthwork must therefore be the mainstay of Famine Relief, and exceptions to this will be so few that they need not be considered at all in this Paper.

III.—What has just been said shows some of the evils connected with small detached works. The difficulty of effective supervision is one great drawback, and another very distinct one is that when works are brought to every man's door many will avail themselves of them who are not

deserving of State Relief. The ryot of a small holding will not, unless hard pressed, start with wife and family to a work twenty miles off. If he does it shows that he is really in want. But if the work be just outside the village, what is to prevent the thriving peasant from sending his wife and children to it while he takes his ease at home, or only comes now and then to amuse himself on the work. He is not the man it is necessary to help.

But supposing he has cattle still alive, who is to tend them if he and all his family are on the Government works twenty miles off? True he may sell them, but they will fetch a very small price and for the country's recovery after the famine is over it is most important to preserve the cattle alive.

When his cattle are dead or sold it is hard to see why the poor fellow should not go off to the Works, and I have often heard it said if he refuses to go twenty miles it shows he cannot be starving. Unfortunately the experience of this last year teaches a different story. It is beyond doubt that many have perished and allowed their children to perish because they would cling to their miserable empty hovels. It is easy to say—'then let them starve.' But he who has actually seen starvation will not say it readily.

Much depends on the season of the year. There are some months when even in ordinary years no agricultural labour is required on dry lands. There is nothing sown, no ploughing, no weeding, no threshing. At such a time it ought to be easiest of all to get the starving cooly away from his village. But even with famine in the land there may be at times odd jobs to be hoped for if he stays at home. The monsoon rains may be due. Clouds may be gathering, and the ryot may naturally think that he ought to be near home to till his patch of land when the rain falls. This is hardly to be discouraged, and yet the poor fellow will go on hoping and starving till he is past all relief.

It may be laid down then that, if possible, relief works should be on a large scale, and that the labour should be massed and detached from the villages. But there should be no hard and fast line drawn. It is even possible that the country may benefit more by the construction of many small works (such as tanks in a hilly country) than of a few large ones.

IV.—I am afraid it cannot be denied that when famines have come on as in India, too often they have found us unprepared. The venerable account of Moses' crowning plague has a significance of its own still.

"And when Pharaoh rose up in the night, he and all his servants, and all "the Egyptians; and there was a great cry in Egypt; for there was not "a house where there was not one dead." This is not much to be wondered at, a strong Government properly discourages overdrawn and sensational reports from its servants, and does not always discriminate whether the cry of 'wolf' is reliable or not. Nor are there very many Government officials who can truly discern the signs of the times, or draw the line between high prices and actual famine.

When the monsoon has been delayed to any unusual extent Executive Engineers should be encouraged to push on works sanctioned and provided for in the Budget. This does not entail on Government much additional outlay. Repairs intended to be done during nine months may perhaps be finished in three. Until the price of provisions rises very much, rates need not be altered, and except that the intervention of contractors should be discouraged the management of the works may go on as usual.

Should the demand for labour be great and the drought still continue some of the projects prepared for famine relief may be started. By this time provisions will likely be dear and rates should be raised, not directly in proportion, but sufficiently so both to support the labourer and his family and to induce him to go on working. For this reason it must be arranged that when one work is finished another should begin, so as to prevent the labourer from returning to his home and to idleness. While he is in full health, a full day's work may be exacted from him. Once let him run down to starvation and Government will not get half a day's work from him.

When the famine has fairly declared itself, and the country has to draw its food supplies from without, then prices will rise and the workman's own labour will not bring in enough for all his family. Then relief works must begin in earnest, but efforts should be made as long as possible to find work for the able-bodied cooly in the ordinary way, and to keep him out of the ranks of the paupers.

V.—I need not write much on the scope of our duties in a famine, for the Famine Commission are likely to lay it down clearly enough. A theory prevailed last year in some places that while it was quite right that the Public Works Budget should be increased indefinitely, and that employment should be found for all the able-bodied still it was no part of its business to take on the half-starved and weak, the town-bred weaver

and the indolent beggar. It was thought a duty to prevent its system being demoralized by dealing with such a vulgar herd as famine paupers: putting its rates all topsy turvy, and occupying its Officers' time with arrangements for feeding babies. Just in this strain I have heard a martinet deplore the slackness of drill in his regiment after a campaign. From what has been already said it will be seen I have no sympathy with this view. Its supporters urge that it is the duty of the District Officers to find work, or at least food, for all except the able-bodied. I should feel little pride in our Department, if I thought it incapable of more than this. During a famine a District Officer has plenty of his own work to do. Cases of postponement or remission of revenue, criminal trials increased tenfold during scarcity, village house to house inspections, road patrolling, relief camps and hospitals, inquiries into the food, stock, and water-supply of the district—all this and far more than this over and above his daily duty is quite enough for him, and in the next famine I hope to see the Exec. Engineer say to the District Officer—"let us share the burden—let me help you wherever I can—you find the workman, and be he ever so weak I will find him suitable work." If we do not get much work out of the starveling surely we shall get as much as the unprofessional District Officer—I do not wish to undervalue works under Civil Agency. They have proved most valuable means of giving relief, but I maintain that they should only be resorted to when the machinery of the Public Works Department has been exhausted, and when it is employing as many as its officers can supervise. Even then the Engineer should do his utmost in advising Civil Officers as to the Professional details of their relief works.

VI.—The management of a Famine Relief Division is a wide subject about which a good deal may be written. It must vary with the style of the work, the condition of the workmen, the intensity of the famine.

The points now to be considered are:—

(*a*). The respective merits of payment by piece work and task work.
(*b*). The sorting and gauging of the labourers.
(*c*). Their tasks.
(*d*). The arrangements for their supervision.
(*e*). The question of Sunday work and payment.
(*f*). The payments.
(*g*). The camp and hospital.

(*a*). By *piece work* payment is to be understood payment for a certain amount of work done irrespective of the time in which it is done, be it half a day or two days. By *task work* payment is meant the payment day by day for a certain quantity of work to be done during the day. The piece work labourer by working twice as hard can earn twice as much every day. The task work labourer by working twice as hard will be finished by mid-day, but he will not be allowed to go on doing a second task.

Primâ facie much is to be said in favour of the piece work system. Its supporters argue that there is no inducement to work like self-interest, that Government will get a better return for its outlay and that enough will have been done for the bulk of the working classes in a famine season if rates are merely eased to meet famine prices. If for earthwork which formerly cost Rs. 1-8-0 per 1,000 cubic feet we now offer Rs. 2-8-0, they argue that the labourer will make an extra push, work extra hours, and will maintain himself and family in their usual independence and without any of the degradation attending pauperism. The advantages of this are self-evident, and when a famine is setting in I would strongly urge that the piece work system should be adhered to as long as possible. But it can be applied with advantage only among the genuine working classes, and these will form after all a small minority of the numbers to be relieved.

The piece work labourer should be allowed to work with his own family or to choose his own earth carriers. He will certainly not choose the weak and sickly who most need help. What are we to do in the vicinity of towns for the weavers and tailors, artizans of all kinds with soft hands and weak backs, as well as for the loafers, vagabonds, and beggars, who however disreputable are not to be allowed to die. We shall have to provide for a large number of women who have never carried a cooly's basket, and all will hold off, some from honourable pride, others from laziness, until their strength is reduced by underfeeding. Work must be found for all these, and all must be paid enough to support life. They will not readily understand piece work, and task work is better suited for them.

One other consideration is, that in famine relief the object is not to finish the work off quickly, but to give useful employment for as long as possible to the greatest number. It often happens that it is very difficult to find good relief work in a district. If the little that there is,

is made over to active piece work labourers, they will finish it off perhaps long before the famine is over.

The conclusion I have arrived at is this, that if the work is to be carried on, famine or no famine, and if it is likely to last the famine out, and if piece work is the system of the place, the Executive Engineer should be instructed to keep on the system as long as he can, and to give every encouragement to the workpeople to join the piece work gangs. But at the same time he must have the task work system too, and the longer the famine lasts the larger will be the proportion of task work labourers.

In Mysore large works were not started until the famine was at its worst. It was found after that that the labourers did not readily take to piece work. Efforts were made to introduce it, but it was not popular and formed so small a part of the relief system as hardly to be worth noticing.

In no case should the system of petty contractors be allowed. They will of course employ only the strong.

(*b*). The sorting and gauging of the labourers is a matter of no trouble with piece work, but it is with task work, and the following remarks apply only to the latter.

It has been asserted to be impossible to have two parties working alongside each other, drawing the same pay and doing different tasks. This I can confidently deny. The able-bodied cooly can be kept at work with a task fully proportioned to his strength, and being paid strictly according to his work alongside of the half-starved weaver getting the same pay for doing half as much, and only being fined a very small amount for short work. I have seen this going on for months with perfect success, but I admit it requires a good deal of arrangement. One of the Engineer's chief difficulties will be to apportion the task to the cooly, so as to get as much out of each as he is fit for, without being too hard on any. His terms must be such as to attract all comers who are really in want.

If relief measures have been taken early and there are many able-bodied workers, a full task should be exacted from them, and as long as it is evident that they can do full work they should be paid rigidly in accordance with it, and fined down to any amount, for not doing their work. But they will often have weakly ones depending on them, and as it is desirable to keep families as much as possible in one gang it has been

found convenient to gang together the moderately able-bodied along with his wife and children, and with the town-bred man who though physically strong is unused to cooly's work; and to exact from the party thus formed 75 per cent. of a full labourer's task. Those doing their full task should be paid on the higher or A scale of wages (to be alluded to further on) and failing to do it they should be cut down to the B or lower rate.

Besides these who may be called the A class there are sure to be many who could never do 75 per cent. of a workman's task: old men and women chiefly, or those who have always been wanting in physique. Perhaps 50 per cent. of a full task may be obtained from these, but very likely not so much. They should be put on light work where it is possible, and be paid on the B scale of wage. It is difficult to fine them for short work without starving them, but where they are incorrigibly idle some little fine may be inflicted.

There is yet a third class, that may be called the Special gang, composed of those naturally able-bodied but who have suffered from famine and the diseases that follow it—gaunt and emaciated lads and girls, men and women in the prime of life with the strength of children, suffering, some from dropsy, most from diarrhœa, and yet better out among the workmen than among the dying in the hospitals. It is clear that no effective labour is to be got out of them, but the true Famine Officer will feel that there is no part of his work more important than looking after these. He must be kindly and yet firm with them; let them rest a good deal, but not let them wander away from the work. It will be useless to task them, but yet even they will do something. They should be paid the full wages of able-bodied labourers while they are in the Special gang, that is enough to buy food not only to support existence, but to get strong on. And most satisfactory it is to witness their gradual return to strength. If as is sometimes the case they are found to be hoarding their coppers and not spending all on food, the Sub-Divisional Officer should give them cooked food instead of wages. Indeed at all times he should have authority to feed them up, if it seems the quickest way to restore them, and to give them milk, meat or vegetables. But this must not be abused.

Mothers with but little nourishment to give to their young babes should be put in the Special gang.

(c).—The tasks.

In earthwork of course these must depend on the hardness of soil; in metal breaking or collection, on the hardness of the stone and its abundance in the neighbourhood.

In earthwork it is best to take as a unit the day's work of the digger irrespective of the lead, a sufficient number of baskets being allowed to each. If the man digs out his full excavation pit he should get his full wage, and if the women and children have not removed the spoil they should be fined, not he. If on the other hand he has failed to dig his full task while they have carried away all that he has dug, it is hard that they should suffer from his laziness, so they should get full wage and he be fined. It will be necessary to regulate carefully the proportion of men to women. Wherever it is possible the members of a family should be employed together. When, as is not infrequent in famine, there is a great majority of women and children, efforts should be made to find suitable work for them without interfering with the arrangements for digging and carrying. Women occasionally volunteer to dig, and do it well, but this is exceptional. At other times they may be employed in collecting road metal and ballast, and in breaking it.

It will not often be possible to measure each man's work every day, or even every three days, but where it can be done, it should be done; where it cannot, the work done by a certain gang must be measured as a whole.

The Sub-Divisional Officer should take particular pains to put this tasking on a good footing. The labourer ought to be made clearly to understand how much is expected from him, and it will not always be easy to do so, when dealing with classes unused to earthwork. There are few things that interfere more with successful Relief Work than careless tasking and reckless fining. The famine cooly should not be set all at once on to a rigid task, and fined for its non-performance, but induced, almost *coaxed* to go on working, the Sub-divisional Officer never forgetting what I have already said, that the relief of the cooly is the first object, not the execution of the work.

And Government will not be the loser by this coaxing. The famine cooly has not much energy or heart for his work, and if he finds that he will not be allowed to starve but will obtain a bare subsistence by doing very little he will often rest content, instead of aspiring to the higher rate of pay, when he would be required to do a tolerable day's work. But Government will be the gainer, if he does earn this higher rate.

It may be looked on as showing either indolence or a distinct want of administrative power when we see extensive fining going on in a Sub-Division, that is when a large party classed as A coolies are day after day receiving only B wages because they are doing short tasks.

When coolies first come on the works they do not readily understand that there are two classes of pay, and it is always best to begin them with the higher and not fine at first for short work, which should nevertheless be measured up. To many officers this laying out of a great number of tasks is almost a new work, and if left to subordinates it is apt to be done in very perfunctory style. It is none the less very important.

(d).—The following is recommended as a convenient system of supervision in a Famine Relief Division—although of course it will vary according to local circumstances :—

Let the whole party be split up into gangs of 50 ; trying as far as possible to keep together coolies of one village or of one family: and where this is impracticable placing them according to their working power. A gangs, B gangs, Special gangs. Over each 50 must be a gangsman, or head cooly, mate, makaddum (or whatever be the local name). In the gang there may be 20 men digging to 30 women and children carrying, or 10 digging to 40 carrying according to circumstances. The gangsman must know all their names and be always with them, keeping them up to their work, and if they do not accomplish their tasks it is not a bad plan to punish him. He need not be able to read or write. To every four gangs there should be one mustering writer who keeps their muster-roll and notes their presence twice a day. He should help also in the payments, and the Executive Engineer should clearly inspect his accounts. The mustering writer is not responsible for the work.

To every six mustering writers, *i. e.*, over 1,200 coolies there should be a sub-overseer, to help in laying out and measuring up work, collecting the muster-rolls, keeping the accounts, attending to the distribution and custody of the tools, and doing all the general duties of a Sub-Overseer. Where cashiers are not employed he must pay the coolies too, and in that case will require a munshi or writer to help him. Over every 48 gangs (2,400 coolies), or two sub-overseers, there should be if possible a European overseer, and on him as on the Engineer must be impressed the difference between a Famine Relief Division and an ordinary one.

Two Overseers with a total of 4,800 coolies are quite enough for a Sub-Division under an Assistant Engineer, and generally three such Sub-Divisions are as much as an Executive Engineer can look after.

Such a complete establishment as this is not often to be had however, and in one time of high pressure in the Bombay Famine of 1877 an Assistant Engineer without a single European under him was looking after 18,000 coolies.

It will be seen that the unit of work is the gang of 50. The other combinations are all multiples of this. A good deal depends on the gangsman. If he is inclined to give trouble he can. The coolies are too ready to believe that in some happy place 20 miles off food is to be had for the asking, and if the gangsman fosters this view, he and his gang may start off some morning. He will be none the worse, but the poor dupes who followed him are apt to be found dead or dying by the road side. If the coolies are encamped it is as well to place the huts of each gang and its head man together.

(*e*). The Sunday question. I wish to approach this from no Sabbatarian point of view, but merely from that of expediency. I maintain then that the work is so hard and constant that unless the Supervising Officers are allowed their day's rest in the week many of them will break down. Regarding the cooly I do not talk so confidently, but I fully believe that he will work all the better for a rest every seventh day, and whether he knows anything of Sunday or not he will appreciate the charms of idleness.

Since the object is to keep him alive in famine however, he must be allowed pay enough on the other six days to cover the seventh. This may either be given (and I think it the best plan) by a small increment to his daily pay, or it may be all given on Saturday evening. The objection to the latter course is that it is difficult to prevent a man coming first to the work on Saturday morning only to get the double pay, and then decamping that night.

When a relief work is first started it may be a good plan to employ the coolies right through the week. Otherwise they are apt to scatter on the idle day, and if they have only begun work on the Wednesday or Thursday they will not have earned pay to support them through the Sunday.

But for the sake of the Officers in charge the practice should be discontinued as soon as possible. Attention may have to be paid to the Special gangs on Sundays. Likely enough they may have spent all their

wages day by day and laid none by for a Sunday meal. This cannot happen if they receive food instead of pay, but generally they prefer the latter.

(*f*). The payments. These must be sufficient to support life, not too liberal to attract a class who require no state help to weather a famine. They must rise as rates rise. Their reduction as rates fall is more difficult.

In the recent Famine in Southern India the rates were partly fixed, partly fluctuating, as follows, and in every case were intended to cover the cost of subsistence on Sundays when the works were closed and no wages given :—

	Man.	Woman.	Working child.	Infant.
In Bombay, ..	1 anna + value of 1 lb. grain.	½ anna + value of 1 lb. grain.	6 pie + value of ½ lb. grain.	3 pie.
In Madras, ..	1½ anna + value of 1 lb. grain.	1 anna + value of 1 lb. grain.	9 pie + value of ½ lb. grain.	½ lb. cooked grain.
In Mysore, ..	9 pie + value of 1⅓ lbs. grain	9 pie + value of 1 lb. grain.	6 pie + value of ⅔ lb. grain.	3 pie + ¼ lb. cooked grain.

The above were the rates for full work, what has been already called the A scale, and this is the rate at which the Special gang should be paid. The B or lower rate of wages may be 6 pie lower for men and women. Working chidren should be on the A scale.

In Civil Relief Works, that is in those superintended by the District Officers and not by the Department Public Works, no one should be paid above the B scale. On these works it is not possible to have the same supervision and precise tasking, and if the wages are as good on these as in the Department Public Works, the coolies will flock to them in preference and earn their livelihood easier.

It is not my intention here to discuss which of these three scales is the best. They hinge somewhat on the still vexed question of whether or not 1 lb. of grain a day is enough to support an adult. But whether 1 lb. or 1⅓ lb. be taken as the basis, some allowance must always be made

for the condiments (vegetables, chillies, turmeric, &c.) which are quite necessary for the healthy native.

When relief works are started, as they should be, early in a famine, and before famine prices have begun to prevail, it will not be judicious to calculate the wages strictly from the price of provisions, should the result be a sum considerably less than the ordinary wage of the country. For instance, supposing that ordinarily a labourer can earn 2½ annas a day, and that relief works are started on the basis of 1 anna and the price of 1 lb. of grain at a time when grain is selling at 20 lbs. per rupee, the the wage will be 1 anna 10 pies, enough it may be to support the hungry man, but probably not enough to attract the labourer used to earning 2½ annas. He will not see why his pay should be lower than usual just when provisions are dearer. He will most likely hang idly about his village, till forced by sharp hunger to accept the offered wage, but at a time when his body is enfeebled by want, and when he can give far less return to Government for 1 anna 10 pies than he could have before for 2½ annas. Depend on it it is good policy to keep the able-bodied from dropping into the ranks of enfeebled paupers, it is the worst of all economy to drive a volunteer from relief works just because he is able-bodied.

I have said it is not very easy to reduce wages as provisions cheapen, and here again the explanation is that the unreasoning cooly is too ready to take a scare, and run away from the works when he is in pretty good case, only to return when he is half starved. It will be found better not to change the wage with every fluctuation of the grain market, and to fix a minimum below which it is not to go, however cheap grain may become as long as it is necessary to keep relief works open at all. Towards the close of the Mysore Famine, the relief works were divided into two classes, those which having been begun it was desirable to finish off, and those which were only kept open from day to day, for the sake of the labourer. In the former were a railway and various irrigation works; the latter consisted chiefly of collecting and preparing road metal, work which could cease whenever the famine ceased. As it was desirable to encourage the labourers to flock to the former, the minimum rates were fixed as follows:—

	As.	P.
For men, ...	2	6
„ women, ...	1	8
„ children, ...	1	2

On the road metal collection minimum prices were fixed:—

For men, ...	2 annas.
„ women, ...	1½ „
„ children above 7, ...	1 „

From my experience it is better to feed small children than to give their parents an allowance for them. But the latter is the easier system of the two, and the real test is whether or not the infants are thriving. The Officer in charge of the works must inspect them frequently. Where an allowance is made to the parent, there is very apt to be fraud practised: women borrowing children to produce at the pay table. And it may be necessary to rule that the wage shall only be granted when the parents live in camp or on the works. Women will not take the trouble to carry their friends' infants to be fed. I have found infants to thrive well on two daily meals, each consisting of 2 oz. of rice boiled in water, with about 1 lb of salt among forty, in addition to what the parents gave them. Should they be thin and drooping the Officer in charge should do his utmost to procure them milk, and if cows are not to be had, he should fall back on Swiss preserved milk. Of course unweaned babes cannot be fed, their mothers may receive an extra 3 pie a day for them.

When coolies arrive fresh at a work they should be paid daily, and indeed as long as this can be managed it should be done, but the burden may be too great for the Officer in charge. As long as there is no cutting for short work and all are paid their full amounts it does not take long to pay large numbers. But it is not easy to measure up work in the evening, to determine how much each individual or each gang is to be cut and then to go on with the payments in time to wind up by dark. Either it is best to cut one day for short work done the previous day, or to pay not in the evening, but the first thing in the morning. Then the Overseer has plenty of time to measure up the work in the evening. Morning payments have another great advantage in securing regular and early attendance. The danger is that a cooly may be prevented by sickness or other good reason for not attending, and he is apt to lose his pay for the preceding day. Without system it may take an immense time to pay 1,000 coolies. With system one cashier may pay from 1,000 to 1,200 in an hour. When the pay time comes gangsmen should separate off those who are to get different wages—all the two anna men, all the

one anna nine pie men, all the working children and so on—and he should give to each a token denoting what pay he is to get. The cashier should be seated at his table with abundance of copper coin before him, all ready arranged, and by his side should be a writer with the muster-rolls. A barrier should be in front of the table, and a second one beyond it, allowing room enough merely for the coolies to pass in single file. They are brought up by their gangsmen, and give their tokens to the writer. He drops them in a box, marks off their names and calls out their pay which the cashier gives them. Of course it is convenient always to pay in sums represented by a common coin: for instance, where single pies are not common seven pies is a troublesome wage to give.

(*g*). The Camp and Hospital.

Where the relief work is close to a large town very likely no camp may be required. If there is one, the coolies will not care to live in it, and will prefer the streets and bazars with their nooks and corners, empty sheds, and deserted houses. But elsewhere camps must be erected. The huts that compose them will vary largely according to the locality, the climate, the materials available. In dry warm weather there is no better camp than a good mango tope. If rain is to be expected efforts should be made to have dry huts for the coolies, for reduced by starvation and nearly naked, they feel the wet, and sickness quickly sets in. In Northern India if work is to be carried on through the cold weather it will be necessary to put the camp in a somewhat sheltered place, and to build huts as far as possible to keep out the bitter cold. In Southern India no such precautions are usually needed. A tolerably water-tight covering will be enough. In any case an open grove of trees should be taken advantage of.

The site of a camp must be selected with judgment. It must be near the work, and near the water supply. It must be so placed that the drainage from about it will not wash down into the source of water supply. The proximity of ravines and dry nullahs is to be avoided, as they increase the difficulties of conservancy. Fuel and provisions must be easily procurable, and if possible thatching grass, palm leaves, or other materials for making huts.

The supply of water must be especially seen to, and should it fail the camp should be moved at once. If the water is drawn from a well care must be taken that the ground round it is kept scrupulously clean and

that the coolies do not wash themselves or their pots in it. Field latrines consisting of long trenches at least 9 inches deep should be daily dug and daily filled in, one for each sex, at a distance of about 500 feet to leeward of the camp, and the Officer in charge must insist on their being used. This is not easily managed for natives are very indifferent about conservancy, but it must be remembered that the inmates of a famine relief camp are peculiarly susceptible to disease, and although the cooly may thrive in ordinary times in his filthy village, as though to prove that bad smells are both wholesome and pleasant, the same indifference cannot be practised with immunity in the relief work camp. Cholera is a frequent companion of famine, and if it bursts out the coolies are likely to flee scared in all directions, carrying infection with them and dying on the road sides. It is therefore quite necessary to keep a conservancy establishment for a camp, and there should be some one person in charge of it who should be punished if the Engineer Officer finds a single bad smell about it.

Dr. Hewlett, Sanitary Commissioner of Bombay, to whom I am indebted for many hints about Relief Camps and Famine Management, recommends camps for not more than 500 coolies in huts holding 20 each. These are placed in five parallel lines 100 feet apart. A space of 50 feet is allowed between each hut in the same line. The huts in the second line stand opposite the open spaces in the first. Surface drainage should be attended to by digging trenches between or round the huts, and the earth may be used to give them a raised floor.

In Mysore the coolies preferred a smaller hut where they could live with their families apart from the others. The pattern adopted (derived from the Ashti Tauk Camp, Sholapur District) had a ground area 9′ × 6′, and was 4½ feet high at the ridge.

The frame work was composed of two pairs of light bamboos, stuck into the ground and tied together where they crossed and a fifth bamboo was used as a ridge pole.

The sides were bamboo mats, palm leaves, grass, or branches of trees, according to circumstances. The back of the hut was built up with a mud wall, and a mat was generally used as a door for the front. One hut was allowed for about three or four coolies, including children. Tolerably good tents may be formed if nothing else is procurable of ordinary native blankets. If pliant bamboos are to be had, round topped huts may be

made like the top of a wagon. Every camp should have some huts run up to serve as shops for banias, to whom every facility should be given for bringing in provisions.

The hospital hut should be altogether a more substantial structure. Fourteen feet is width sufficient for two rows of patients. The sides should be low walls about 4 feet high with a good pent roof. The length of one ward should not exceed 50 feet. If beds are not procurable for the patients it is well to have raised plinths for them to sleep on, and the rest of the hut should be strewn with clean sand frequently changed. A little whitewash on the walls will not cost much, and will vastly improve appearances. Hospital provision should be made for at least ten per cent. of the camp. Of course there must be separate huts for each sex, and in the case of a large camp likely to stand for some time it is well to have a spare hut for contagious diseases, cholera, smallpox, &c., and a small one for a dead house. The hospital must be placed on the most healthy site near the camp. The Medical Subordinate must have a hut close at hand, and he will require another for his medicines and stores. He will be responsible for all connected with the sick, but he will do his work all the better if he sees that the Engineer in charge is interested in it, and is in the habit of frequently visiting the hospital and looking after the patients.

A burying ground must be selected at least a quarter of a mile to leeward of the camp with sufficient soil to bury 6 feet deep, and two or three graves ought to be always ready dug. Cholera patients should be buried speedily after death, in the clothes they were wearing. Dr. Hewlett advises that a camp should be abandoned if more than three cases of cholera occur in it.

VII.—Lastly, we have to consider the course to be adopted at the close of a Famine, a season nearly as welcome to the fagged relief officer, as to the impoverished ryot. It must be remembered that a famine cannot be closed by order of Government, and that abundant rain and broad acres of fresh ploughed land and young corn do not necessarily give immediate relief. Where the distress has been of short duration these symptoms of returning prosperity will give relief, for grain stocks will probably be still in the country, and they will be produced and prices will fall whenever there are pretty certain indications of a good harvest ahead. But when the famine has lasted long, it is probable that the grain stocks

have been exhausted, and that until the young crop has not only started fair, but has been matured, food will be nearly equally scarce and equally dear; while the people are month by month getting poorer, and less able to buy at famine rates.

It may be laid down then that famine relief works must go on, until prices have very much fallen. The numbers that flock to the works will diminish to some extent, but perhaps not very much.

The cultivator will employ some labour on weeding his fields, but he will be too poor to employ nearly as much as usual.

The rain will have brought forth various wild fruits, from which the poor will derive a scanty sustenance, and they will often prefer living thus to toiling at the Government work. But many will still remain on the works, and the object of the Engineer must now be to bring them back to the normal rules of the Department without inflicting hardship on them.

The first thing to do is carefully to separate the able-bodied from the weakly, and to work them apart, treating the former in the ordinary way on piece or task work, only allowing them a higher rate on account of the prevailing famine prices. They may not readily take to this *régime* for they are too apt to become demoralised after being watched and looked after for months, but it must be insisted on.

Having disposed of these able-bodied ones the weakly should be classified according to their strength, and the Special gangs in particular should be massed at certain places where the work is suitable, where a good hospital can be organized, and where they may be specially looked after. The value of their work will of course be small, and if the District Officers have facilities for taking over these specials altogether the Engineer may dispose of them. But generally I think it will be found a fairer share of the relief work to leave them in the hands of the Engineer. As the coolies regain their strength they should be steadily drafted into the able-bodied gangs.

There need not now be the same dread as formerly of driving them off the works, for the coolies will have got better used to our ways, and will not be so easily frightened: while if they do go away, things are not so desperate as before, and they are not likely to die of starvation. Nor need there be the same anxiety as before about applying the distance test. Works will be finished by degrees, and at this stage it is not desirable to

open new ones. So the coolies should be told if they want more work they must go some distance to it, and if they are used to their Officer and trust him, as they should, it will be easier than before to induce those to move whom it is desirable to keep on.

Week after week these Special gangs should become fewer. Some will return to their villages, some will recover, many will die. When the State aid can be withdrawn from them altogether, will, as has been said, depend very much on the prices in the market, but as these cheapen private charity will begin afresh, and many of the Specials will resume their old begging habits. If the gangs gradually disappear altogether this will be the most satisfactory conclusion to the Famine Relief Works, and the hard-worked Famine Relief Officer will be well deserving of a rest.

C. C. S. M.

No. CCLXXXVI.

BABUL WOOD AS LOCOMOTIVE FUEL AND ITS EFFECTS.

By Major A. LeMessurier, R.E., *Offg. Under Secy. to Govt. of India, Railway Branch.*

[Enclosure to P. W. D., No. 3126 R. of 1878.]

When the Sind Railway was first opened, coal was used as fuel. In 1872 wood obtained from the Sind forests (babul) was resorted to. The use of wood as fuel was abandoned on 7th March 1875, and coal was again substituted. Certain comparisons were made from time to time between the actual cost as fuel of coal and wood, and in 1874 the Depy. Consulting Engineer in Sind (No. 1470 of 11th October 1874) to Consulting Engineer, Lahore, stated that, taking all matters into consideration, it would appear that the Railway Company is using wood-fuel at a rate roughly represented by coal at Rs. 30 per ton.

Early in 1875 the crown-plate of the fire-box of Engine No. 16 was found cracked while running. The mileage performed since a new boiler had been put in being 24,819 with coal and 33,738 with wood. The crown-plate of No. 1 Engine, originally $\frac{3}{4}''$, which had done about the same amount of work, was at once cut open, and it was found that its thickness varied from $\frac{1}{8}$ to $\frac{1}{12}$ of an inch.

Engine No. 19 was also stopped in its work for fear of evil results; the thickness of the crown-plate was found to be $\frac{1}{10}$th of an inch after a mileage of 36,328 with coal and 36,745 with wood.

It had never before been known that the copper of the fire-boxes had so quickly worn away, and from a critical examination it was found that the damage appeared chiefly in the crown-plate; the tube-plate was more or less affected, and the sides apparently were unharmed. The conclusions arrived at from the position of the damaged parts were that the injury had been caused by pyroligneous acid, in the form of vapour.

These serious results, considered with the very high cost (para. 1 ante) of wood as fuel, decided the Agent to abandon its use and to return to coal. This was done on 7th March 1875.

The subject was referred to the Chemical Analyser in Bombay, who was unable to say with certainty to what cause the extensive oxidation was due.

Information was sought from the experience gained by other lines using engines burning wood-fuel, and the replies received seemed to show that wood caused less injury to boxes and tubes by the gases given off, than coal. The information collected, with samples of the wood and saw-dust, was submitted to the Chemical Analyser, who found that, although babul contained a high percentage of acid, yet the mango wood in use on the Oudh and Rohilkhund contained it in a higher degree, and consequently the results obtained on destructive distillation appeared to him to negative the theory that the corrosion in the Sind fire-boxes had resulted from acid vapours formed during the combustion of the wood as fuel. Appendix No. I.

The Board of Directors in England submitted the question to the opinion of Dr. Watson. His evidence is, " that the more rapid destruction of the copper plates of the fire-box during the use of babul wood than during the use of coal as fuel is due to the presence of more chlorine in the wood used than in the coal, and further that babul wood is in this respect very much worse than many woods, and sensibly worse than any European wood " to the analysis of which he had access—Appendix No. II.

Appendix No. I.

From—*The Chemical Analyst to Government.* To—*Deputy Consulting Engineer for Railways in Sind. No.* 129.

Dated 6th March 1877.

I have the honour to acknowledge receipt of your letter No. 136 of the 21st ultimo. The information in regard to the Oudh and Rohilkhund Railway engine forwarded with your endorsement No. 1008 of the 4th December last, appears to me to completely negative the theory that the corrosion noticed in the Sind Railway engines resulted from acid vapours formed during the combustion of the wood used as fuel.

If you refer to my letter No. 538 of the 9th October, you will see that the percentage of acid yielded on destructive distillation by mango wood,

the fuel employed on the Oudh and Rohilkhund Railway, is considerably larger than the percentage of acid yielded by the babul wood employed on the Sind Railway. At the same time the report of the Locomotive Superintendent of the Oudh and Rohilkhund Railway, covered by your endorsement No. 1008, shows that no corrosion similar to that found in the Sind Railway engines has been noticed to occur in an engine of the Oudh and Rohilkhund Railway, in which mango wood was the principal fuel employed. The conditions, moreover, under which the wood was burnt in the Oudh and Rohilkhund Railway engine are stated to be "essentially the same" as the conditions under which wood was burnt in the corroded engines of the Sind Railway. In face of these statements, I do not see how it can be maintained that acid vapour from the wood-fuel was the cause of the corrosion in the Sind engines.

APPENDIX No. II.

From—*The Secretary of State for India.* To—*The Government of India.*
No. 70R.

Dated 5th July 1877.

With the letter to the Agent, No. 960 (para. 11), the Sind, Punjab and Delhi Railway Board forwarded a copy of a report (with accompaniments) by Dr. Watson, relative to the effect of babul wood on copper fire-boxes.

Copies of these papers are herewith sent for your Excellency's information, and in order that you may direct experiments to be made and further investigation, should you consider it desirable.

n—*G. P. Bidder, Esq., Secy., London Board, Sind, Punjab and Delhi Railway.* To—*W. P. Andrew, Esq.*

Dated 17th April 1876.

I have pleasure in handing you Dr. Watson's report on the corroded fire-boxes, vouched for as it is by the authority of Dr. Percy, whose letter is appended, together with Mr. Kirkaldy's mechanical tests, which indicate that the copper was of the usual standard of quality.

The evidence, therefore, appears strong that the usual amount of common salt present in the wood was the cause of the decay, and certainly points to the advisability of avoiding the use of babul wood as much as possible.

From—*Dr. John Percy.* To—*W. J. Kingsbury, Esq.*

Dated 16th April 1877.

I return herewith Dr. Watson's report, which has much interested me. He is a very accurate and trustworthy analyst, and I think he has obtained pretty satisfactory evidence in support of his conclusions. To me the results are quite novel and remarkable.

From—*Dr. David Watson.* To—*W. J. Kingsbury,*

Dated 10th April 1877.

I must apologize for not having replied to yours of the 29th ultimo before this. I hardly know what to say to your query about the action of the babul wood gases on iron tubes. I should imagine that somewhat similar results would obtain in the case of iron as in the case of copper, but the temperature of the gases in the tubes of a boiler must be, except at the extreme fire-box end, very much less than in the fire-box itself, so that one cannot argue from what goes on in the fire-box to what goes on in the tubes. In illustration of this, it is customary to find the interior of the brass tubes of a locomotive boiler coated with a green oxy-chloride of copper that would be converted into a substance similar to that I found in the fire-box, if in contact with a red hot flame. The reason why brass and copper boiler tubes go at the fire-box end is, doubtless, because there the gases passing through the tube are hottest.

I have arrived at the conclusion that the greatest temperature of the plates of a locomotive fire-box when in use cannot be very much less than 300°C.

I cannot find that anything is known from actual experiment as to this point.

Dated 23rd March.

Report by Dr. D. Watson, on the deterioration of the copper fire-box plates of the Sind, Punjab and Delhi Railway Company.

I have the honour to present my report on the above subject.

To assist me in my investigation, I had a sample of babul wood and portions of the corroded plates of a fire-box that I inspected at Mr. Kirkaldy's, Southwark. Also a portion of a spark-catcher, with regard to which unusually rapid wear had been noticed. I had, further, copies

of correspondence between the officials of the Company and others on this subject.

The deterioration of the plates was by actual reduction of thickness, which, according to the reports sent me, occurred in a manner and with a rapidity unknown where coal is used for fuel.

In the case of the fire-box which I examined, the plates were originally $\frac{3}{4}$-inch and $\frac{1}{2}$-inch thick, and were worn down over the whole internal surface, chiefly on the crown and tube-plates.

The wood which I received as a sample of that employed as fuel appeared admirably adapted for that purpose, being in billets about 18 inches long and 3 to 4 inches in diameter. It is hard and dense. The specific gravity of some pieces cut from billets that had been exposed to the air of the laboratory for a fortnight was, in three samples,—

1	..	..	·789	mean ·810
2	..	..	·796	
3	..	..	·844	

The wood is not resinous, and requires a good draught for ready combustion.

I found the internal surface of the plates covered in places with a pulverulent deposit, which I found to be merely sand, and here and there a green incrustation; both of these were evidently deposits accruing after the removal of the plates from the boiler. Besides these, and adhering closely to the surface of the copper scale, was a substance resembling ordinary copper. This was evidently a substance produced during the corrosion of the plates. The surface of the copper when the scale was removed, was, as a rule, not smooth, but more or less pitted.

As a result of my investigations, I have to report that the rapid destruction of the plates in question is due to the presence of chloride of sodium, as one of the mineral constituents of the babul wood used as fuel.

Chloride of sodium is present in a very much larger quantity in babul wood than in ordinary coal.

Babul wood yields 2 per cent. ash, which contains 75 per cent. of chlorine. The sample of babul had necessarily had a sea voyage, and to avoid error from the chloride of sodium deposited from the atmosphere, the chlorine was determined in the ash of portions from the centre of billets forming the sample as well as from saw-dust from cuts taken directly across them.

Comparing babul wood, in this respect, with coal, we find that coal does not contain, except exceptionally, more than traces of chlorine. In the analysis of 23 samples of the ash of coal, given in Dr. Percy's Metallurgy, none occurs in which the ash was found to contain more than traces of chlorine.

The following gives the amount of chloride of sodium and of chlorine in various samples of the ash of wood, analyses of which are quoted by Dr. Percy in his Metallurgy. We see by comparison that, in this respect, babul wood is the least suitable for use as fuel in a copper fire-box.

	Chloride of sodium.	Chlorine.
Beech (1), ...	trace	·0
„ (2), ...	·87	·53
Pine	trace	..
Fagus sylvatica, ...	·21	·13
Larix Europica, ...	·92	·56
Quercus robur, ...	..	·01
Vine (1), ...	·083	·05
(2), ...	·058	·035
Compare these with babul—		
Saw-dust, ...	1·260	·764
From interior of billets, ...	1·213	·736

In the rapid combustion of the locomotive fire-box, the alkaline chloride of the fuel is carried forward with the products of combustion. At the high temperature of the flame, and in the pressure of aqueous vapour, the chlorine of the chloride of sodium comes in contact with the plates of the fire box as hydrochloric acid.

From experiments I have made for the purpose of this investigation, I found that a rapid corrosion and formation of scale occurs when air, containing traces of hydrochloric acid, comes in contact with metallic copper at temperatures much lower than the lowest at which scale is formed, with any degree of rapidity, in air free from hydrochloric acid.

The scale thus produced differs from the scale resulting from the ordinary oxidation of copper in air, by containing chlorine. This chlorine is not entirely removed by subsequent heating to much higher temperatures.

I therefore expected to find a proportion of chlorine in the scale adhering to the internal surface of the corroded fire-box.

The scale was analysed, and found to contain on two examples—

No. 1, ... 3·439 per cent. of chlorine.
No. 2, ... 2·936 „ „

The spark-catcher was almost free from scale, which had apparently been formed and mostly detached. Enough, however, remained to enable me to detect chlorine as one of its constituents. The samples for analysis were taken from scale closely adhering to the metallic surface, all loose deposit or incrustation having previously been removed. Any danger of being misled by a deposit or incrustation arising subsequent to the removal of the plates from the boiler was thereby obviated.

Though the amount of chlorine in the wood is apparently so insignificant, it is an amount adequate to the part it is supposed to play. If we assume that 10 cwt. of copper are removed from the plates of a fire-box before they are rendered useless, and that all has been converted into an oxidized scale containing 3 per cent. chlorine, we find that the total amount of chlorine the whole of the scale will contain is about equal to that contained by only 113 tons of babul wood. I do not mean to say that the burning of 113 tons of wood would destroy the fire-box. Of course, only a portion of the chlorine of the fuel comes into contact with the plates of the fire-box at all, and only a portion of that which does so remains in combination in the scale.

The quantity of wood burned in the fire-boxes that were destroyed must have been many times 113 tons. I may safely assert, therefore, that, so far as the amount of chlorine is concerned, the cause alleged is adequate to the effects observed.

The rapidity with which copper will scale under the circumstances depends in great measure on the temperature at which it is exposed to the gases. Hence those parts of the fire-box which are hottest when in use are most corroded. Thus the centres of the portions of the plates between the bolts are more corroded than those portions surrounding the bolts, and the crown and tube-plates are more corroded than the side and back plates. There is a case mentioned in one of the letters submitted to me, No. 1072 of 1875, from T. G. Newnham, in which an accelerated destruction was noticed as the engine continued in use. This may be explained by assuming that the water side of the plates became covered with a gradually increasing thickness of deposit, and that from that cause the temperature of the plates as the boiler worked, became as time went on gradually higher.

The very rapid destruction of a spark-catcher, referred to in letter No. 2848 of 1875, from T. G. Newnham is due, doubtless, to it having,

from its position, been constantly at a temperature above that of the plates of the fire-box that were less rapidly corroded.

I am satisfied, from the above considerations, that the more rapid destruction of the copper plates of a fire-box during the use of babul wood than during the use of coal as fuel is due to the presence of more chlorine in the wood used than in the coal; and further, that babul wood as represented by the sample provided me, which seemed a very sufficient one, being three tons in all, is in this respect very much worse than many woods, and sensibly worse than any European wood to the analysis of which I have access.

I find no other circumstance in the composition of babul wood, or in the change of conditions arising from the substitution of wood fuel for coal, to account in any degree for the observed increased rate of destruction of copper fire-boxes when babul wood is substituted for coal as fuel.

Extracts.

From—*T. G. Newnham, Esq., Acting Deputy Agent.* To—*The Deputy Consulting Engineer for Railways in Sind, Kurrachee, from letter referred to above.* No. 1720 *of* 1875.

5th April 1875. "I have the honour to inform you that the copper crown-plate of the fire-box of No. 19 Engine is as much worn as those of Nos. 1 and 16, *viz.*, to about $\frac{1}{10}$th inch in thickness. Wood has now been in use for three years and upwards, and the thickness of the crown-plate of No. 19 was $\frac{3}{8}$-inch in September last. It thus appears that the pyroligneous acid *acts but slightly upon the copper for a time, but at last most rapidly, causing it to come away in scales.*"

From—*T. G. Newnham, Esq., Acting Deputy Agent.* To—*The Deputy Consulting Engineer for Railways in Sind, Kurrachee.* No. 2848 *of* 1875.

Sept. 20th 1875. "A spark-catcher made of copper plate, 5′ 6″ × 1′ × 5″ × $\frac{1}{8}$-inch thick, perforated with $\frac{1}{4}$-inch holes, was reduced to one-third of this thickness after the engine had run 14 trips."

Correspondence.

To the Editor.

DEAR SIR,—I have the pleasure to send you by dâk, a little Contrivance for the speedy adjustment of a Theodolite plummet in a vertical direction over a peg. I used it on the Survey for the Extension of the Punjab Northern State Railway, and found it saved me a great deal of time, and am therefore led to think it might usefully be made known to others.



The Contrivance only consists of a small piece of brass with two slanting holes drilled through it. The plummet string is passed through these two holes and looped round and fastened to the brass again.

I may remark, that it works better if the piece of brass chain and hook which ordinarily depend from the under side of a Theodolite for the purpose of suspending the plummet, is taken off and a rigid hook put on in its place. Over this the loop of the string is passed and the piece of brass A is moved up or down with the fingers, according as it is desired to lower or raise the plummet. The friction of the cord in the slanting holes holds it in any position.

Yours faithfully,

FRED. M. AVERN,
Exec. Engineer, Indus Tunnel Division,
Punjab Northern State Railway.

