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PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING.

[SECOND SERIES.]

EDITED BY

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[SECOND SERIES.]

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No. CCXIV.

NEW GOVERNMENT COLLEGE AT LAHORE.

[*Vide* Plates I. to IV.]

Building designed by W. Purdon, Esq., *M. Inst.* C.E., *Engineer.*

Constructed by Rai Kunhya Lal Bahadur, *Assoc. Inst.* C.E., *Exec. Engineer, Lahore.*

The new Lahore College is built as per plan accompanying, (*Plate* IV.) It contains accommodation for a College, Zillah School, and Normal School, with a large Examination and Lecture Hall, and two large rooms, one for Library, and the other for Models, &c.

The College and Zillah School consist of 12 large class rooms 30′ × 20′ each, and 4 small ones 20′ × 15′ each, or 16 in all, of which, 8 are in the lower, and 8 in the upper story.

The Normal School has 4 large class rooms 30′ × 20′ each, and 4 small ones 15′ × 20′ each, or 8 in all, of which 4 are in the lower, and 4 in the upper, story. The two rooms beyond the Normal School, each 30′ × 18′, connected by a wide arch, are to be used as Library, and Model room, and the rooms above these in the upper story, will be used as Principal's and Assistant Principal's rooms. The Examination and Lecture Hall is 55′ × 35′, with a gallery 10 feet wide all round, access to which, as well as to the upper rooms of the Normal School, and the Library, is given by means of pucka masonry staircases, in two small rooms (at the back of the hall) 10′ × 10′ inside. Access to the upper rooms of the College, and Zillah School is given by means of a wide staircase, in an octagonal tower, at the north-west corner of the building. The connecting passages, and the verandahs, are 10 feet wide throughout.

The building is constructed according to the following specification.

SPECIFICATION.

Foundation.—After the ground which the building is to occupy, is properly cleared and levelled, the foundations to be marked and excavated, and properly dressed to about 12 inches wider (on both sides) than the brickwork. The bottom of the excavations to be carefully levelled, and dressed, and then, three feet of concrete (consisting of one part of kunkur lime siftings, one part of súrkí, and one part of good fresh burnt kunkur lime, well mixed, watered, and turned over with shovels) to be given in layers of six inches each, well rammed and thoroughly consolidated; each successive layer being given while the lower one is wet. When the concrete bed is finished, the top layer to be properly levelled, and masonry of small bricks laid in good kunkur lime mortar, to be executed as per dimensions given on plan. After the masonry of the foundations is finished, the extra space dug on both sides of the walls, to be carefully filled with earth, *well* rammed, so as to leave no hollows close to the foundations. The concrete bed is necessary, owing to the loose nature of the soil of the foundations, which has been ascertained by excavations made for the purpose at places on the site. Good firm soil is met with at a depth of 12 feet below the surface, and on this account, the foundations are made 13* feet deep, of which, three feet is to be concrete, and the rest filled with pucka masonry.

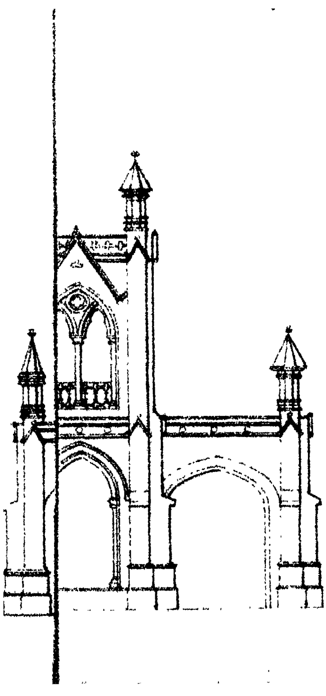
Foundations of steps to be two feet deep below the surface, of which, one foot is to be concrete work, and one foot filled with pucka masonry of small bricks.

Plinth.—After the foundations are finished in the manner described above, the thickness of walls in the plinth to be carefully marked on the top of the masonry of the foundations, leaving an offset of three inches on either side.

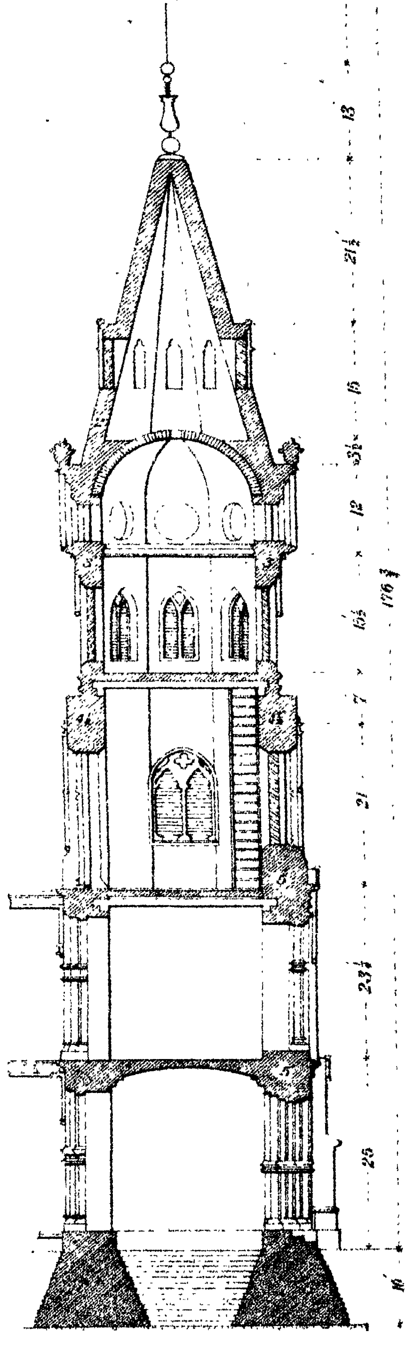
The plinth to be built of small pucka bricks, laid in good kunkur lime mortar; the plinth of the outer walls being faced with large 9″ × 4½″ × 3″ bricks, thoroughly burnt, and well shaped, and properly cut and dressed, and laid in Flemish bond, with close joints.

Steps.—The steps to be of large pucka bricks, carefully cut, and laid on edge, in good kunkur lime mortar, (made of nine parts of kunkur and

* The foundations of the tower are 15 feet deep, 5 feet of which is of concrete, and 10 feet of pucka masonry.



SECTION THROUGH A.B.



one of stone lime,) with close joints, and rubbed smooth. The outer edge of the steps to be chamfered.

Floor of lower rooms and verandahs.—The floors of lower rooms and verandahs to consist of well burnt flat tiles, 12″ × 12″ × 2½″, carefully dressed and laid in good lime mortar, (same as for the steps,) with fine joints, and the whole rubbed smooth and even. The tiles of the floors to rest on six inches of pucka masonry of small bricks, over six inches of concrete, well beaten and consolidated.

The filling in of earth below the concrete, to be well rammed.

Floor of upper rooms and of gallery and verandahs.—The floor of upper rooms, passages and gallery, to consist of planks 1½ inches thick, and of the verandahs to be made of lime terrace, four inches thick, well beaten, over a layer of flat bricks or tiles, resting on sound and well seasoned deodar wood kurries and beams, the former having a rest of nine inches, and the latter of 18 inches on the walls, on continuous wall plates, except where there are chimneys. The ends of the kurries and beams resting on the walls, to be coated with tar, laid on hot, and a clear space of half an inch to be left round them for the free circulation of air. The beams to be 18″ × 10″ laid four and a half feet from centre to centre for the main rooms; 18″ × 10″ four feet from centre to centre for the small rooms; 18″ × 12″ six feet from centre to centre for the square tower; and 14″ × 7″ five feet apart, for the verandahs, passages, and gallery. Kurries for main rooms, verandahs, passages, and gallery, to be 5½″ × 3″, for small rooms 5″ × 3″, and for the tower 6″ × 4″, all one foot from centre to centre.

Masonry of Superstructure.—The outer walls, outer face of inner verandah walls, and all the exposed parts of superstructure, to be of large, sound, well burnt, and well shaped bricks, 9″ × 4½″ × 3″, carefully dressed, and laid in Flemish bond, with straight and fine joints. The outside brickwork to be very carefully dressed, and the mouldings and ornamental portions to be properly and neatly executed, as per plan, and the whole of the dressed brickwork to be rubbed smooth and even.

The bricks to be *well* soaked in water for two hours* previous to being put into the work, and the mortar to be made of the best fresh burnt kunkur and stone lime, in the proportion of nine parts of the former to one of latter, thoroughly mixed, and well ground in a mortar mill.

* *Vide* Punjab Specifications.

The masonry to be well grouted after every course of brickwork, and every day's work to be flooded with water in the evening, so that any crevices left in the brickwork, may be filled with mortar. The tops of unfinished walls to be also kept covered with water till they are finished.

Pucka plaster, inner.—The superstructure to be pucka plastered and whitewashed inside; the mouldings round the inner pillars and archways of the Examination and Lecture Hall, together with the cornice of the hall, to be executed roughly in brickwork, and finished off neatly in "*gutch*," or sulphate of lime plaster, which makes a very good cement for interior decorations of structures. The "*gutch*" plaster to have a thin coat of fine white lime (made of chips of white marble burnt for the purpose) rubbed smooth and even. The plaster of the rest of the walls to be made of good lime mortar, made of nine parts of best kunkur lime, mixed with one part of fine stone lime, and the whole well ground in a mill. The whitewash for the inside, to be made of pure white lime, strained twice through a cloth, and laid on in two or three thin coats, till the walls become pure white.

The slender mullions, tracery of the windows, and the columns supporting the north-west spire, to be of black stone, obtained from the hills at Chineote, in the Jhung District, and the bosses and pinnacles, &c., of both the towers, to be of red sandstone obtained from Agra or Delhi, and cut to the proper size and shape as per plan.

Roof.—The roof of the verandahs, gallery, and passages, to be flat, on deodar beams 12″ × 6″, at five feet apart from centre to centre, over which, are to be placed kurries 5″ × 3″, one foot from centre to centre, overlaid with flat pucka tiles 12″ × 12″ × 2½″, covered with four inches of lime terrace well beaten, and finished with a coat of mud plaster one and a half inches thick.

Roof of class rooms to consist of large slates, laid with an overlap of eight inches, over deodar planking one inch thick, resting on deodar battens 3″ × 2″, one foot apart from centre to centre.

The trusses to be as per plan, and laid five feet apart from centre to centre.

Boarded ceiling to be given under the purlins and collar beams.

Roof of Examination and Lecture Hall to be same as above, the trusses being 11 feet from centre to centre.

The Examination and Lecture Hall to have also boarded ceiling under the collar beams, and purlins, which is to be ornamented with mouldings in keeping with the inside of the hall.

The square tower to have a pucka masonry spire, faced with slates on the outside, so as to be in keeping with the roof of the class rooms and lecture hall. The octagonal tower to have also slate roof on deodar rafters and battens.

The spire of the square, and roof of the octagonal towers, to terminate in stone pinnacles, and iron finials (as per plan), gilt at top.

Ventilating windows with venetian shutters to be provided (as per plan) in the spire of the square tower, and the main slate roof of the building to have two large ventilating shafts.

Scantlings of main timbers of roofs and floors, to be as per following detailed calculations:—

CALCULATIONS OF SCANTLINGS OF BEAMS FOR ROOFS AND FLOORS, &c.

I. *Flat roof of verandahs, passages, and gallery of lecture hall.*

Span, ... = 10 feet.
Intervals between beams from centre to centre, .. = 5 „
Weight per foot, superficial, ... = 100 lbs.
Then, weight acting at centre of beam, or W = 10 ×
5 × 100 × ·5 = ... = 2,500 „
Strength of beam 12″ × 6″ = $\frac{b \cdot d^2 \times 500}{10 \times 10}$, ... = 4,320 „

II. *Floor of verandahs, passages, and gallery of lecture hall.*

Span, ... = 10 feet.
Intervals between beams from centre to centre, .. = 5 „
Weight per foot, superficial, including weight of men, &c., = 200 lbs.
Then, weight acting at centre of each beam = 10′ × 5′
× 200 × ·5, ... = 5,000 „
Strength of beam = 14″ × 7″ = $\frac{b \cdot d^2 \times 500}{10 \times 10}$ =
$\frac{7 \times 14^2 \times 500}{100}$ .. .. = 6,860 „

III. *Floor of class rooms 30′ × 20′ each.*

Span, ... = 20 feet.
Central interval between beams, ... = 4 „
Weight per foot, superficial, including weight of men, &c., = 200 lbs.

Weight acting at centre of beam $= 20 \times 4 \times 200 \times \cdot 5$ = 8,000 lbs.

Strength of beam, 18″ × 10″ $= \frac{18^2 \times 10 \times 500}{10 \times 20}$ .. = 8,100 „

IV. *Floor of class rooms 20′ × 15′ each.*

Span, ... = 15 feet.
Central interval between beams, ... = 6·66 „
Weight per superficial foot including weight of men, &c., = 200 lbs.
Weight acting at centre of beam $= 15 \times 6 \cdot 66 \times 200 \times \cdot 5$ = 9,990 „
Strength of beam 18″ × 10″ $= \frac{18^2 \times 10 \times 500}{10 \times 15}$ .. = 10,800 „

V. *Floor of square tower.*

Span, ... = 18 feet.
Central interval between beams, ... = 6 „
Weight per superficial foot including weight of men, &c., = 200 lbs.
Weight acting at centre of beam $= 18 \times 6 \times 200 \times \cdot 5$ = 10,800 „
Strength of beam 18″ × 12″ $= \frac{18^2 \times 12 \times 500}{10 \times 18}$ .. = 10,800 „

VI. *Trussed roof over class rooms.*

Span, ... = 20 feet.
Rise, ... = 14·0 „
Central interval between trusses, ... = 5 „
Weight per superficial foot of roof, including pressure of wind, &c., ... = 150 lbs.
Then, slanting height of roof $= \sqrt{10^2 + 14^2} = \sqrt{296}$ = 17 feet nearly.
Weight acting vertically at apex of roof =
$\frac{2 \times 17 \times 5 \times 150}{2}$ lbs., ... = 12,750 „
$= \frac{W}{2}$

Strain in direction of rafter $= \frac{W}{2}$ cosec : of angle of inclination of rafter $= \frac{W}{2} \times \frac{\text{Length of rafter}}{\text{Rise of roof}} =$
$12,750 \times \frac{17}{14}$ .. .. = 15,482 lbs.

Sectional area of rafter, should, therefore, be $\frac{15482}{\frac{1}{2}\text{* of } 700}$ = 44 square

* The unsupported length of rafter being between 12 and 24 times its least thickness, half the resistent only is taken into the calculation.

inches = 9″ × 5″ or 45 square inches; the scantling given, *vide* plan, 9″ × 6″, will, therefore, be ample.

Strain on tie-beam = 12,750 × $\frac{\text{Half span}}{\text{Rise of roof}}$ = 12,750 × $\frac{10}{14}$ = 9,107 lbs.

Sectional area of tie-beam, should, therefore, be $\frac{9107}{\frac{1}{2}\text{ of }700}$ = 26 square inches, or about 5″ × 5″ only, but as the tie-beam has to sustain the weight of a boarded ceiling also, its scantlings have been made 12″ × 6″ as per plan.

Strain on king-post, ... = 12,750 lbs.

Sectional area of ditto = $\frac{12750}{\frac{1}{2}\text{ of }700}$ .. .. .. = 36 sq. inches.

The scantlings given on plan are 8″ × 6″, or 48 square inches at the weakest part.

Strain on braces = $\frac{12750}{2} \times \frac{\text{Length of brace}}{\text{Rise of brace}}$

$\frac{12750}{2} \times \frac{9}{7}$ = 8,200 lbs. nearly.

Sectional area of brace, should, therefore, be $\frac{8200}{\frac{1}{2}\text{ of }700}$ or 24 square inches.

The scantlings given on plan, are 6″ × 6″, or 36 square inches which is ample.

Purlins to be 6″ × 4″ at 3½ feet from centre to centre.

Ridge pole 9″ × 5″.

Common rafters 3″ × 2″, one foot apart from centre to centre.

VII. *Trussed roof over examination and lecture hall.*

Span, ...	=	35 feet.
Rise, ...	=	27 ,,
Central interval between trusses, ...	=	11 ,,
Weight per superficial foot of roof, including pressure of wind, and weight of trusses and ornamental wood-work, &c., ...	=	100 lbs.
Then, slanting height of roof = $\sqrt{17{\cdot}5^2 \times 27^2}$, ..	=	32 feet nearly.
Weight acting vertically at apex of roof = $2 \times 32 \times \frac{11}{2} \times 100$,	=	35,200 lbs.

Strain on rafter = 35,200 × $\frac{\text{Length of rafter}}{\text{Rise of roof}}$ =

35,200 × $\frac{32}{27}$ .. .. = 41,718 lbs.

Sectional area of rafter $= \frac{41700}{700} =$ 60 inches nearly, which gives scantlings of 10″ × 6″. Scantlings given, are 12″ × 6″.

Strain on king-post = 35,200, and its sectional area =

$\frac{35200}{\frac{5}{6} \text{ of } 700}$ .. .. = 60 {inches nearly.

Scantlings given, 9″ × 6″ at weakest part.

Strain on tie-beam $= 35{,}200 \times \frac{7}{10}$ .. .. .. = 24,640 lbs.

Sectional area of beam $= \frac{24640}{\frac{1}{2} \text{ of } 700}$ .. .. .. = 70 {sq. ins. nearly.

Scantlings given, 12″ × 6″, or 72 square inches.

Vertical strain at head of braces $= (32 \times 11 \times 100)\frac{1}{2}$ = 17,600 lbs.

Length of each brace $= \sqrt{4{\cdot}5^2 \times 3{\cdot}25^2}$ .. .. = 5·5 feet.

Strain on each brace $= 17{,}600 \times \frac{5{\cdot}5}{4{\cdot}5}$ .. .. = 21,511 lbs.

Sectional area of brace $= \frac{21511}{\frac{5}{6} \text{ of } 700} =$ 36 square inches, which gives the scantlings of braces at 6″ × 6″.

Weight on each unsupported portion of purlin $= 11{\cdot}4 \times 100 \times {\cdot}5$ .. .. = 2,200 lbs.

Strength of above portion of purlin $= \frac{10^2 \times 6 \times 500}{10 \times 11}$ = 2,727 lbs.

Weight on each unsupported portion of common rafter $= 4 \times 1 \times 100 \times {\cdot}5$ .. .. = 200 lbs.

Strength of above portion of common rafter $\frac{3^2 \times 2 \times 500}{10 \times 4}$ = 225 lbs.

The scantlings of the various pieces may, therefore, be as follows:—

Principal rafter, ...	12″ × 6″
King-post (in the middle), ...	9″ × 6″
Tie-beam, ...	12″ × 6″
Braces, ...	6″ × 6″
Purlins, ...	10″ × 6″
Common-rafters, ...	3″ × 2″
Ridge pole, ...	12″ × 6″
Wall plates, large, ...	6″ × 4″
„ „ small, ...	4″ × 3″

Vertical pieces for ornamental panelling,	.. ..	6" × 6"
" " "	.. ..	6" × 4"
Horizontal pieces for "	.. .. ..	12" × 6"
Framework of panelling,	.. ..	2½" thick.
Panels,	.. ..	1" do.

The above scantlings will be ample, as the best picked deodar wood will only be used for the woodwork of the roofs.

Doors and windows.—The doors and windows to be made of sound and well seasoned deodar wood, 2¼ inches thick, with mullions ¾-inch thick; joints to be accurately fitted, and dimensions to be as per plan. The doors and windows to be glazed as shown on plan, (except the upper windows of the towers, which are to be venetian,) to be fitted with English bolts, and hung on English hinges. The fanlights to be made to open and shut for purposes of ventilation.

Pucka cornice.—The outer and inner cornices to be made of dressed pucka masonry of large bricks, set in good kunkur and stone lime mortar, with fine joints, and the mouldings cut properly in bricks.

Ironwork.—The railings in the archways of the upper story, and the finials of the two towers, to be made of iron, properly worked, and the finials to be gilt at top.

Painting and varnishing.—All the woodwork of roof and floors, doors, windows, venetians, &c., to be properly varnished, of tún wood colour. Iron railings to be painted black, or of slate colour.

Fixtures.—A wooden staircase with railings, to be provided in the square tower, and the whole of its woodwork to be properly fitted, and varnished. Punkahs with hooks and ropes to be provided for all the rooms.

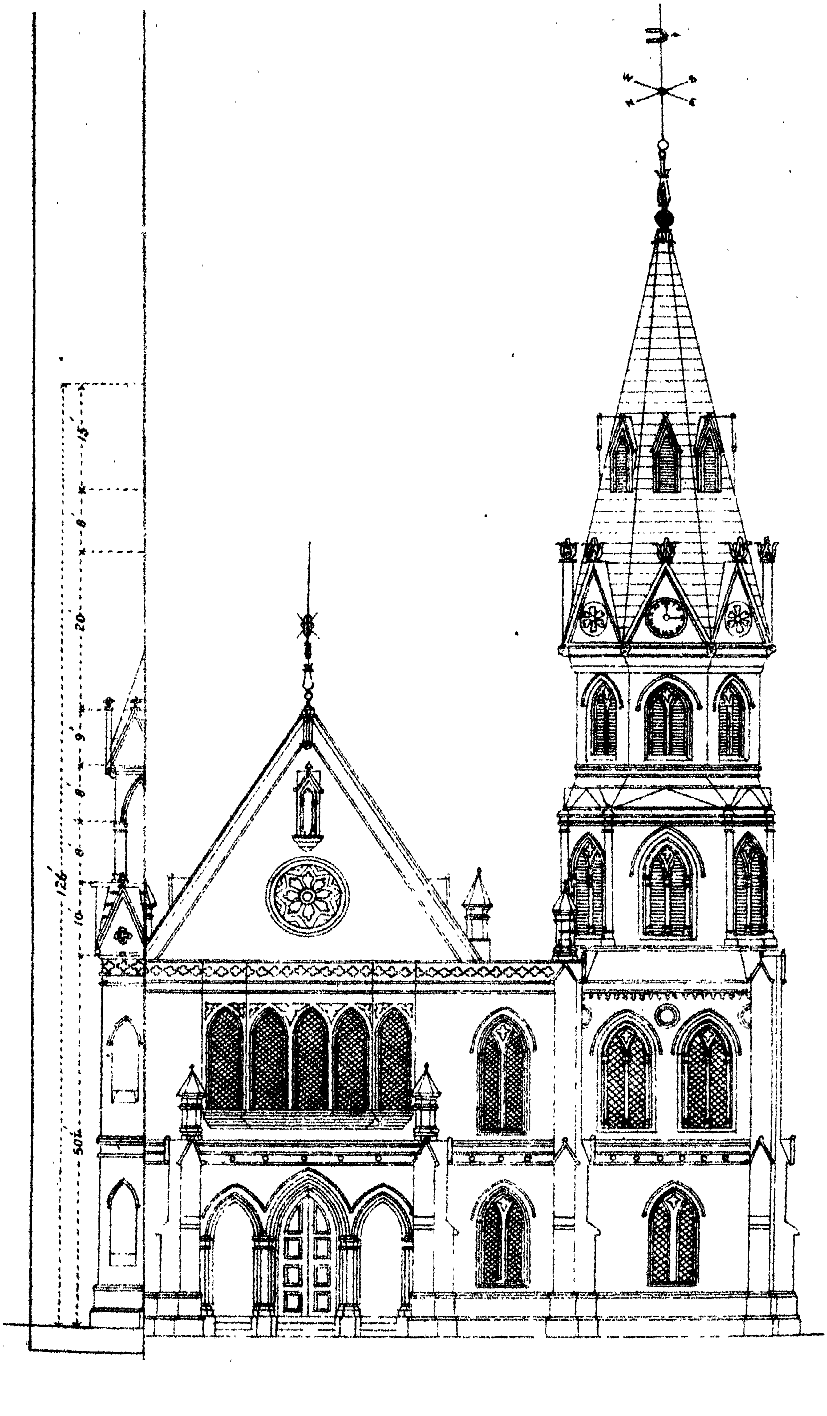
The work to be carried on as quickly as practicable, after date of commencement. And after completion, all the rubbish and spare materials to be removed, and the ground trimmed, and the whole place made tidy and put in a proper state, to be made over to the Educational Department.

Abstract of Cost of New College and Normal School at Lahore.

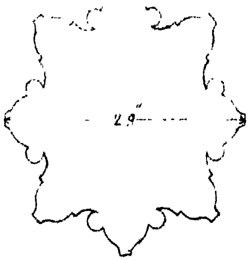
Earthwork.

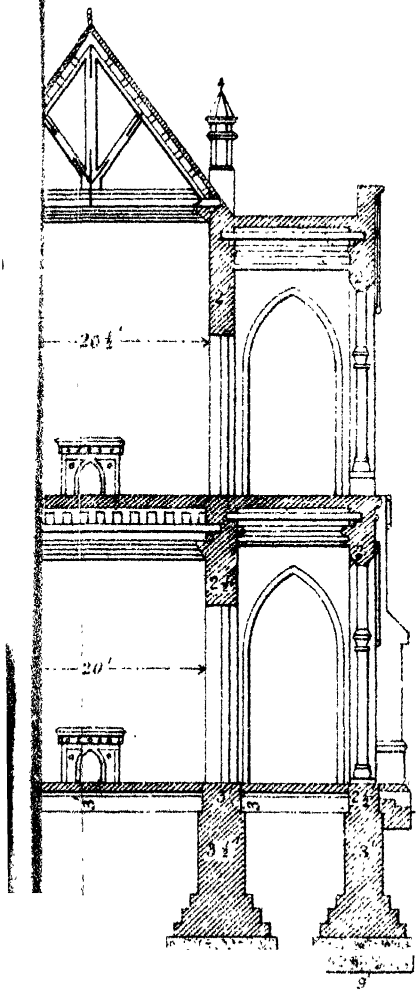
c. ft.		RS.
3,94,122	Excavation of foundation, at Rs. 3 per 1,000, ...	1,182
8,73,720	Earthwork of approaches and filling low ground, at Rs. 4 per 1,000,	3,495
	Carried over, ..	4,677

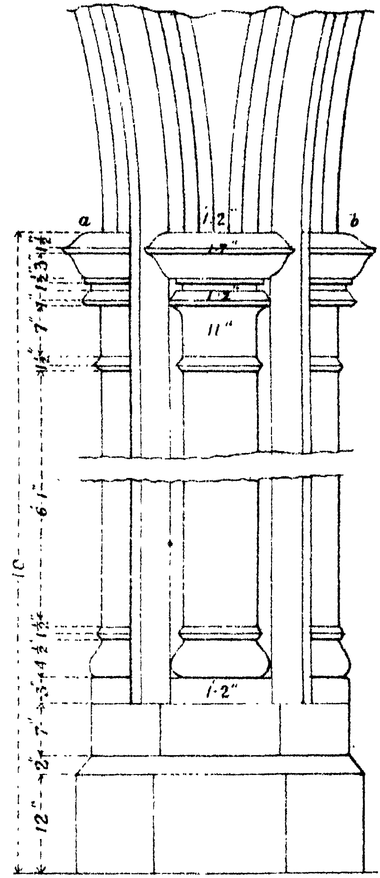
	Brought forward, ..	4,677
s. ft.		
1,58,500	Turfing of ground, at Rs. 3 per 1,000, ...	476
	Clearing rubbish after completion of work, at Rs. 3 per 1,000,.	565
	Road Metal.	
c. ft.		
23,850	Brick foundation of approaches, at Rs. 4 per 100, .. .	954
23,850	Kunkur metal of approaches, at Rs. 8-8 per 100, ...	2,028
	Bricklayers' Work.	
90,955	Concrete work of foundation, at Rs. 14-12-6 per 100, ...	13,444
1,18,161	Pucka masonry of foundation, at Rs. 18-5-10 per 100, ...	21,701
28,475	„ „ plinth, at Rs. 26-3-2 per 100, ...	7,460
3,883	„ „ steps, at Rs. 34-0-9 per 100, ...	1,322
	„ „ superstructure, at Rs. 36-13-6 nearly, ...	1,04,423
r. ft.		
7,764	Inner cornice, at Rs. 0-4-½ per foot, ...	1,952
4,982	Outer cornice, at Rs. 0-13-2 per foot, ...	4,089
2,219	Dressed outer mouldings of upper story, at Rs. 0-6-5 per foot,..	896
c. ft.		
732	Ornamental parapet, at Rs. 56-11-1 per 100, ...	415
	Flooring and Roofing.	
s. ft.		
20,272	Tiled floor of 1st story, at Rs. 16-11-5 per 100, ...	3,388
7,342	Tiled floor of 2nd story, at Rs. 18-12-9 per 100, ...	1,380
11,563	Flat roof covering of porches, and upper verandahs, &c., at Rs. 11-15-8 per 100, ...	1,385
	Plastering and Whitewashing.	
s. ft.		
77,654	Plain inner pucka plaster, at Rs. 4-12-6 per 100,..	3,713
14,395	Ornamental plaster of moulding of hall, at Rs. 11-3-2 per 100,..	1,612
	Fine plaster of mouldings of hall, at Rs. 5-1-8 per 100,.. ..	1,138
77,654	Whitewashing, plain, at Rs. 0-4-2 per 100, ...	202
36,688	„ rubbed smooth of do., &c., at Rs. 3-3-10 per 100,	1,189
	Masons' Work.	
c. ft.		
1,258	Red stone work, including carriage, at Rs. 4-13-8 per foot, ..	6,081
4,245	Chineote stone work, including carriage, at Rs. 7-3-5 per foot, ..	30,630
	Slaters' Work.	
s. ft.		
22,635	Slate roof covering, at Rs. 47-13-6 per 100, ...	10,840
2,390	Slate facing of spires of towers, at Rs. 26-14-6 per 100,.. ..	643
	Carpenters' and Joiners' Work.	
11,601	Boarded flooring of 2nd story, at Rs. 28-10-6 per 100, ...	3,350
12,196	Doors and windows, at Rs. 1-7-3 per foot,..	17,755
	Carried over, ..	2,47,507

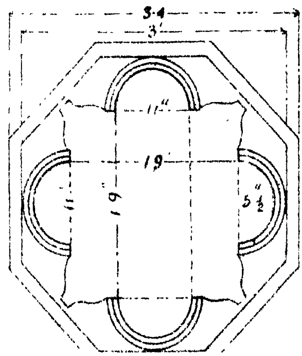

W
S
N
E
15'
8'
20
9'
8'
8'
10
126'
50'

ORIZONTAL SECTION ON *a.b.* FIG 3 — ENLARGED ELEVATION OF PILLAR









		RS.
	Brought forward, ..	2,47,507
No.		
2	Ventilating shafts, at Rs. 251 each, ...	502
s. ft.		
16,282	Boarded ceiling of slate roof, at Rs. 0-3-8 per foot nearly, ..	3,900
22,635	Planking under the slates, at Rs. 0-3-3 per foot nearly, ...	4,647
2,487	Punkahs, at Rs. 0-8-1 per foot nearly, ...	1,244
149	Wooden staircase, at Rs. 3-0-0 per foot nearly, ...	447
c. ft.		
112	Very long timbers for trussed roof, at Rs. 3-13-1 per foot nearly,	428
594	Long timbers for trussed roof, at Rs. 3-4-8 per foot nearly, ..	1,955
3,850	Short timbers for trussed roof, at Rs. 2-2-5 per foot nearly, ..	8,284
1,950	Long timbers for wooden floor, at Rs. 3-3-5 per foot, ...	6,266
533	Short timbers for wooden floor, at Rs. 2-4-6 per foot, ...	1,217
334	Long timbers for flat roof, at Rs. 3-5-8 per foot nearly, ...	1,120
1,801	Short timbers for flat roof, at Rs. 2-2-9 per foot nearly,.. ..	3,910
4,489	Burgahs and wall plates for flat roof and wooden floor, at Rs. 1-12-6 per foot nearly.	7,789

Smiths' Work.

s. ft.		
1,225	Iron railings, ornamental, at Rs. 3-13-3 per foot, ...	4,692
r. ft.		
404	Iron ridging, at Rs. 2-12-0 per foot, ...	1,110
mds.		
100	Iron for trusses of hall, at Rs. 25-0-0 per maund,..	2,500
150	Iron for trusses of other rooms, at Rs. 21-0-4 per maund, ..	3,256
No.		
2	Lightning conductors and clock, ...	4,000
2	Iron finials for towers, at Rs. 250 each, ...	500
	Total Rupees, ..	3,05,274
	Add contingencies, at 5 per cent., ...	15,263
	Grand Total Rupees, ..	3,20,537

K. L.

No. CCXV.

RAILWAY DIVIDENDS.

BY MAJOR T. F. DOWDEN, R.E., *Assoc. Inst. C.E.*

IN the following paper, the author has endeavoured to summarise a few of the leading points which have come under his observation during the last five years in connection with the economy of railway construction and working, while employed in the Consulting Engineer's department under the Government of Bombay.

The rate of progress and expansion of the system of Railways in India, under a guarantee from the Indian Treasury, being a matter at the present time depending almost wholly on the dividends received, must make it an object of the first importance to ascertain all the leading principles which directly affect the dividends, and it is very certain that some are apt to be overlooked. It is not the object of this paper to refer to the considerations which may render a railway desirable at all, or to the political and commercial reasons that may influence those considerations in its location.

They must all, however, be more or less subordinated to the ways and means, and provided there is scope for the operation of railways and capital forthcoming to make them, the first object is then to secure capability in exact proportion to the requirements, at least cost for greatest durability in construction, with facilities for working at a minimum expense.

The author experiences some diffidence in treating a subject on which so little appears to have been written, and does not claim to do more than put forward a short paper embodying the views he has been led to form with the amount of information at present open to him.

The subject is such a wide one for investigation, and has so many ramifications, that it is extremely difficult to avoid diffuseness and stick to leading points. It is very certain that errors of detail, involving large sacrifices of capital and dividends, must occur, unless the leading principles of railway practice are clearly understood. Just as it is necessary to proceed from the great triangulation of a survey to the smaller, and from thence to the field survey and plane table to make all parts fit in, so it is necessary in the case of railways to fix the bearings well before we start, and it is proposed in the present Essay to indicate some of those principal bench marks which must of necessity come more familiarly under the eye of the Engineer than of the financier.

Railway Dividends.

The net earnings depend on—

A. (i). The gross receipts from the work done;

(ii). The gross expenses for doing the work;

the difference between these constitutes the net earnings.

The dividends which may be declared with a given net earning depend on the amount of capital sunk in providing the machinery.

B. The capital necessary for providing the machinery consists of—

(1). Cost of actual constructive works (labor, materials, supervision, &c.);

(2). Cost of land, law, compensation, &c.

The former (1) is alone concerned in the matter of the power or capability of the machinery to do the desired work at least cost, and on which both the gross earnings (i), and gross expenses (ii), must largely depend, and it is highly essential, therefore, that economy and skill should be specially secured in all construction. It is the particular province of the Engineer to endeavour to attain as near to perfection as possible in regard to these matters, and seeing the importance of the subject, it is not to be wondered at that projectors should hasten to avail themselves of the best engineering talent procurable.

It is very clear, therefore, that for financial success, capability of machinery must *at least* be in proportion to the cost of it, other things being constant, but it will, perhaps, be seen further on, that by careful adaptation of the size of the machinery to the work to be done by it, capability may be got at a diminished cost per unit, the larger the number of units of work to be done, by transferring as large a proportion of the work as possible from *labor* to the mechanical agency of *heat* and the *durability of materials.*

An axiom, well understood, lays it down, that a machine should be proportioned to the work it has to do, and all the parts of the machine should bear a constant proportion to one another and the whole, which it is as well to bear in mind.

It is very evident, therefore, that in considering any of the elements which go to affect the dividends, and which may be grouped under three principal heads—

(i). Gross receipts;

(ii). Gross expenses;

(iii). Cost and capability of the machinery;

we shall fall into error if we neglect to consider the influence which an alteration of those elements under any one head will have on the dividends, through the action exercised on elements comprised under any of the other principal heads.

As regards the cost of land, law, compensation, &c., in construction (2), the charges form amounts depending on the comparative prosperity of the country, the demand for land and absence of legislation for acquiring it at a market value apart from the special value conferred on the land by the demand for railway purposes. These charges, while they in no way go to increase the capability of the lines for work, result in a large diminution of the dividend from a given net earning; on the other hand, those net earnings may be sustained at a high figure by the high rates which a rich and prosperous people may be in a position to pay for transport. Still, it cannot be conceded that high rates are in the interest of the community generally, and the only way that low ones could be secured with highest dividends would be by legislation transferring the burden of the unproductive capital cost to the public generally, but this could only be done with a system of railways constructed and worked by the State in the interest of the public.

The advantage of State agency would not be fully realised except by legislation to restrict excessive compensation and to simplify the law processes, &c. This would benefit the community at large, though it might restrict the area of individual private gain from railway construction. The transfer to the State of all the existing English railways at the average market rate of all the stocks, would apparently not be attended with extraordinary difficulty, and would not probably involve a larger interest payment than the average present net earning of all the railways taken together; and, indeed, as Government could raise money cheaper than private companies, it is very probable there would be a margin of profit.

C. If the construction capital B (1) really represents the economical capability of the line for executing a given quantity of work in a fixed time, it is evident that with a fixed construction capital spent in appliances, the gross receipts cannot be increased by augmented quantity of traffic, for the line cannot carry it. But the receipts may be increased from increased rates, provided the number of units offering be not in consequence diminished, and there is no limit to the rates which companies may charge in their own interest, but that which tends to prevent the line receiving the full quantity of traffic for which it is designed.

But it is possible by capital additions to increase the capability of lines, often in a greater percentage ratio than the percentage ratio of increased cost. Such capital additions generally take the form of improvements and new inventions, which are legitimately brought to bear to increase the capability and consequently the receipts, but the limit to their introduction is when the expenses of working are increased by them in the same or a greater ratio than the interest of the capital cost of them. This is not seldom the case where the additions or inventions tend to throw too large a proportion of the whole work *per unit* on to *skilled labour* in working. A striking exemplification of this can be found in the number of accidents on over-worked lines attributed to the fallibility of human agency, and which would have been avoided in a system combining a greater proportion of mechanical efficiency and certainty per unit of work done, only obtainable through a proper proportion of lines of rails, sidings, &c., for a given quantity of traffic on a given gauge.

D. What we want to know, therefore, is—the economical capability for a given capital.

It must clearly mean that quantity of traffic which gives least cost per unit conveyed, consisting of working expense (*a*), and interest on the cost of construction (*b*), taken together.

It must also be clear that under these circumstances alone can the dividend be largest, provided the rates are maximum fixed, but not higher than will admit of the line receiving the full economical quantity of traffic for which it is designed.

It is hardly necessary to point out that scarcely any railway company can tell what the cost of carrying their units of traffic is, and they must therefore be working in the dark as regards the best effect their capital expenditure is capable of producing in regard to dividends, if carefully watched in every particular and adjusted to the number of units of traffic offering, under all circumstances, so as to render the employment of least labour necessary per unit, and to transfer the largest portion of the whole power required for all the units to the agency of machinery, at the same time taking care not to provide more machinery than will render the charge for interest on the cost of it *per unit* least.

E. Now as regards rates which may be charged, these depend on the demand for accommodation and the powers possessed by companies through monopolies to restrict it by high charges.

In the absence of monopolies, it is certain that competition must sooner or later tend to provide new lines, and reduce profits where they are high, till a level of the ordinary rate of interest for good security is reached. With the abolition of monopoly, which would result from a comprehensive State system of railways, excess profits over the ordinary rate of interest for good security would disappear in the reduction of rates and fares, which it would be to the interest of every individual in the country to obtain.

Not only are the public at present charged too high for the service rendered, owing to the monopoly of the highways by private persons, but the very dividends coming to these persons are severely diminished by the excess capital charges under the system which has obtained for land, compensation, &c., B (2), which are estimated to have amounted, in England, by some authorities, to one-third of the total expense of the lines.

The only part of the excess fares charged the public by the companies, which is recovered by the country, is the passenger duty. A duty on locomotion cannot be a good thing in itself, but could not be foregone under the circumstances. It is, however a concurrence of the country in a form of tax tending to restrict development, which might have been better sustained in the shape of interest on cost of land, &c., acquired for State railways.

This waste of power, which could only have occurred in a country overburdened with activity and riches, calls for attention now that there is a general dullness of trade and a want of employment for capital and labour.

The evils of unpunctuality and dreadful accidents chiefly occurring on the overtaxed lines, though they have occupied the attention of all authorities for years, have necessarily proved irremediable; the system of capital expenditure under which they have been produced would sufficiently account for them.

We know well how the best energies have been brought to bear on the signalling department, on points and crossings, telegraphy, and other machinery, all of which has seriously gone to increase the element of human fallibility, while at the same time increasing the working expenses for labour and also the capital cost of the lines, whereas perhaps much more real efficiency and safety would have been gained by an expenditure of capital for new or relief lines, sidings, &c., on a less complicated system of working; the dividends would very probably be increased by the proceeding, especially where companies can borrow for constructive works at the *market rate of interest*, and through them obtain a power of earning at a *monopolist rate*.

It is well known that machinery can effect work cheaper than labour, yet much energy appears to be lavished in increasing the proportion of labour of the lines, while economical capability of performing the work through the agency of durable works, materials and machinery is withheld, merely to save the interest on the capital.

The fallacy of supposing it possible to close the capital accounts of a Railway with a growing traffic will be very evident from the above considerations.

F. Now to consider the economical capability as defined under letter D. It is as certain there is a fixed limit to it as that there is a limit to the weight a given girder will bear, the load a horse, donkey, or man will draw at given speeds, &c. If this limit is not attained on the one hand, or is passed on the other, there will inevitably be increased expense, or loss of power somehow or another.

G. The *rates* may first of all be eliminated from the question of capability of the works, and then we have simply this definition for the limit. "That quantity of traffic which gives the least cost per unit conveyed, the cost being made up of working expenses (1) and interest on the cost of the works (2)."

(*a*). If there is *little or no traffic* on the line there will still be a large charge for *interest* on the cost of the works. The cost per unit will be a *maximum*.

For *working expense.* There is every facility provided for the cost per unit to be a *minimum.*

(*b*). If there is *no railway.*

For *interest* on cost of the works. The cost per unit will be a *minimum.*

For *working expense.* The cost per unit will be a *maximum.*

If there *is* a railway and *some* traffic we must get all the gradations of cost per unit conveyed between the limits of (*a*) and (*b*), according to the size and cost of the railway and the quantity of traffic over it.

H. With an increase of traffic from *nil* to a maximum for a given railway, the cost per unit of traffic for *interest* will diminish; and if there were no difference in the *working expense* per unit, with varying quantities of traffic, there would be no limit to the quantity of traffic we should not seek to impose.

But the contemplation of an unlimited traffic is first of all opposed to the axiom that a machine should be proportioned to the work it has to do, and would imply an advantage in an excess of capital expenditure for a given quantity, which is contrary to what we assume as desirable; and secondly, there is a large difference in the cost of working units in proportion to their number for a machine of given size.

If a railway is to be made to work only a single unit, it must be maintained. The charges for this form a considerable item in the expenses, independent of the work. Then there are charges for direction, management, and establishments, without which a single unit could not be conveyed. In fact the expenses may be wholly divided into two great classes—

(*c*). One containing all those depending for their amount on the work actually performed;

(*d*). The other comprising all those depending for their amount on the scale of construction.

Under the former head (*c*) may be classed every expense caused by the actual movement of trains, and these principally comprise the following items, stated in the proportions which at present seem to the author to result under the most favorable conditions:—

Head (*c*).

Train Staff, ...	1	
Repairs of permanent way, ...	1	due to work done.
Carried forward, ..	2	

Brought forward,		
Maintenance of rolling stock, ...	0½	due to work done.
Fuel, ...	2	
Grease, oil, waste, &c., ...	0¼	including cleaning
Train stores, ...	0¼	
Total,		
Head (*d*). Repairs of permanent way,		due to size of works and weather.
Rolling stock, ...	0½	Do.
Administration of all departments,	1	
Miscellaneous, repairs of buildings, &c.,	1	
Station staff, ...	1	
„ water for locomotive engines,	0¼	
„ stores for traffic department,	0¼	
Total,		
Grand Total, ..	10	

I. Now it is possible with a given scale of construction, to alter the proportions of expenditure under these two great divisions.

First to consider if too few trains are run.—If only one train was run in a day, the expense under (*c*) would be small compared with that under (*d*). Endeavours would then be made with considerable success in such cases, to reduce the charges under head (*d*) to a proportion with the small charges under head (*c*); but it would be impossible to take off anything for repairs of permanent way and rolling stock due to time and the weather, which would be in proportion to the scale of the construction, or to bring down the other charges to a low enough proportion with so small a quantity of work, and there will be an excess cost per unit in this class of items at least, and the inference must be that the line has been constructed on too large a scale. With an increased number of full trains the charges under this class per unit will continually diminish up to a ertain point, while the charges under head (*c*) for the movement of trains vill, up to that point, not be materially altered per unit.

Next if too many trains are run with a given proportion of rolling stock, it would result in a higher average velocity of all trains in order to get through the work in the time, and this means an increase in all the charges except train staff under head (*c*) per unit performed.

Again, if the line has been designed with too large a proportion of olling stock for the accommodation of an excessive traffic, and a single accident occurs involving the replacement of capital lost and payment of compensation from revenue which might have been avoided with a smaller number of trains running, an excess cost per unit will have been occasioned traceable to the smallness of the scale of construction, or disproportion of parts, and the excess will appear under nearly all the items of expense in class (*c*) while at the same time some charges for excess work under head (*d*) must also be increased, notably "station staff," "water," "stores;" also the durability of the permanent way and rolling stock will be materially affected with a disproportion of capital expenditure on the one or other for a given railway.

Unless *durability* is attained, either by limiting the work, or increasing the size of the machinery, and consequently its capital cost, so as to make the repairs equal to the interest of money, there must be a loss in working expenses more than regained by insufficient capital expenditure. The loss makes itself apparent through the withdrawal of parts of the machinery for too frequent renewal, or the keeping up of a larger stock than would otherwise be required, if the work is not to be interrupted to effect the renewals, and this applies particularly to the rolling stock; while, as regards the permanent way, the frequent renewal of rails, &c., evidently causes the labour and carriage of the materials to the site to form so much a larger proportion of the whole cost than if less frequent renewals were necessary, and besides that, there is a great waste of time of men endeavouring to keep the way in order between too rapidly following trains, and often the work has to be done at night at the expense of increased wages.

J. It is in the adjustment of the size of the machinery to the work to be done that we have the power of reducing both the great classes [H (*c*), (*d*),] and each of the sub-divisions to a minimum.

The smaller the scale of construction of the whole machinery the smaller will be the charges under head (*d*); but with reduced size, restricted capability follows in proportion, and with a given capacity, the number and size of the trains is a fixed quantity, and if this be the case, the gross charge (*c*) depending on it must also be a fixed determinable quantity, and the charges under head (*d*) depending on the size of the machinery as a whole, must also be proportioned to the charges (*c*) which depend on the number of units of work done.

K. But neither class of charges per unit can be constant, for it is well known that economy results from the employment of larger machines, if there is full work for them according to their capacity. To recognise the truth of this, we may take an example.

If a cart and horse with a single driver will suffice to take one ton a given distance, it will be cheaper per ton, to convey two tons in a larger cart even employing two horses; for not only will the same driver perhaps do for both, but in the case of the larger cart, the additional strength and weight of the vehicle will not add double the dead weight to be hauled. Neither the mechanical work nor the human labour required will be so great per ton of freight. Exactly in a similar way does the size of machinery lead to the economy of mechanical or human effort in every case.

The larger the machinery, the cheaper the cost of doing a unit of work with it. But the financial success of machinery demands that no more capital should be sunk than will just provide facilities for doing the total number of units. Here at once is prescribed the practical limit of cheapness which it is possible to attain, for it depends evidently on the number of units of work forthcoming for machinery to be employed upon.

It will be too great a divergence here to attempt to examine the difference of cheapness for different sized similar machines, but the sum of it appears to be the substitution of the maximum paying amount of mechanical for human agency in doing the work and dividing the remaining human effort for working over the greatest number of units of paying work, but restricting the machinery to the exact size required to complete them, and no more.

L. The whole expense of working or production is then made up of *interest on the capital representing the annual cost of the least quantity of mechanical power that will suffice* D *(b), and the cost of the minimum amount in working and maintaining that power* D *(a)*, and for these two classes of cost to be both least, the size of the machinery must be so limited, and its mechanical efficiency so perfect that each may be half the whole, or interest must equal the working expense.

If mechanical efficiency per unit is to be obtained in proportion to the capital expended per unit, and the power of the machine to do a given number of such units can be made in proportion to the whole capital, then the greatest effect per unit with least size of the whole machinery will result, when equal amounts of capital are expended in "efficiency" on the one hand and "sufficiency" on the other.

With greatest efficiency per unit ensured, the least expense of producing a unit must result, and with a capital sufficient, but not in excess of the requirements for the whole number of units, the cost of sufficiency per unit for interest must also be least.

When efficiency and sufficiency per unit are equal, the machinery is exactly suited to the work, and the test of all of them will then be when the working expenses equal the interest of the cost of construction, and the least total expense for both interest and working expense taken together will result.

Thus it appears, that when the machinery is perfectly worked—working expenses will equal interest on construction, and—the charge under head (*d*), paragraph H, sometimes called "*fixed charges*," will equal those under head (*c*), usually called "*train*" or "*movement*" charges.

All the subordinate heads, both of "construction and working accounts," will undoubtedly also have direct relations to one another for the best effect; some of them have been attempted to be investigated by the Author in his "Notes on Railways," which it is not possible to introduce here.

It also appears that better classes of machinery may be employed with greater effect, the larger the number of units of work to be done by them.

M. Now this all agrees with what we know of machinery in general, and all mechanical appliances. As regards construction, an instance may be taken of the progressive improvement of means of transport.

If a single unit has to be conveyed, it is highly probable that it may be done by an ordinary labourer without any preparation whatever, who will do it cheapest. If more, then a wheelbarrow may be brought into operation, with a few improvements in the road, the addition of a plank or two, &c., &c. Next, a horse may possibly find sufficient employment, and if many loads have to be taken, we may invest in a cart and improve the surface of the road to lessen the traction, which, while it has the effect mechanically of increasing our horse power, does so at an expense for the replacement of hard material in the road, instead of a greater one for the keep of horses and men in doing a great part of the paying work. From single horses and carts we may proceed to macadamised surfaces, and teams and wagons, always improving in every direction equally, so as to keep down the human agency and animal power as low as possible, yet endeavouring, all we know, to improve the road surface and gradients to augment the power of those elements to the utmost consistent with the capital outlay warranted by the number of paying units.

In this way we find it cheaper, as the traffic increases to widen the roads, bridge, and metal them. Finally we come to railways, the most efficient machinery yet invented for general transport purposes, which can be made on a small scale or increased in size to suit the traffic, and then we apply engines instead of horses, and iron and steel instead of road metal to sustain the work.

N. If it is true that machinery should, in whole and in part be proportioned to the work it has to do, all the parts of a Railway should for the best effect be proportioned to the gauge.

Efficiency and sufficiency will be best provided for when the gauge is as the square root of the "work" to be performed by it, whether that work be the overcoming of friction, wind, or gravity.

For, in order that least cost per unit of work, and least cost of machinery, may occur, it is necessary to proportion the size of the machinery so that it may always be fully employed, and no more or less, as long as any expense is being incurred for it. To proceed to fix the size is a mere matter of arithmetic. The whole traffic being given, it may be divided into a given number of trains a day of fixed size, weight, and speed. They must each have a complete length of line blocked clear, within which trains would be under complete control, and all the line clear lengths must have single trains running on them throughout the entire day, since wages are paid by the day. In this way the whole machinery will be working at its maximum of efficiency and safety, while the expenses varying with the size of the line H (d) should proceed at equal rates with the expenses (c) for the movement of units and the whole number of units required will be completed in the day's work.

By this arrangement we shall have the smallest train loads that will suffice for the whole traffic, and it remains then only to adjust the gauge so as to provide engines of given power with maximum stability for least distance between the wheels. A great deal has been said in regard to the precise gauge most suitable to a given quantity of traffic. It is evident that the gauge can only be accepted as a standard measure of the capacity, if all the constructive parts bear the same proportion to it, in the particular railways compared, for with any alteration in the best form for the application of materials to construction, loss must occur somewhere.

The principles which determine the gauge with reference to the engines, also determine the size of the vehicles from the gauge. The durability they should have will be attained by the disposition of a certain weight of material in best form, affording sufficient capacity with greatest stability. With greatest durability of the rolling stock the smaller the number of vehicles and engines that will be required, but there is a limit to the durability desirable when it is to be attained by a *per contra* increase in working expense owing to an excessive quantity of material being employed; such expense will make itself apparent under nearly every head of the revenue account H (*c*), and besides that, there is a loss in such a case, of some capital uselessly sunk in the excess material. On the other hand, too light or unstable a construction for given loads of freight leads to undue wear, and also to the same necessity for a larger stock of vehicles than would otherwise have been required, to provide for the withdrawals for more frequent repairs; the unstability or lightness also render it impossible to maintain the same speed as could otherwise be adopted, and consequently with a given amount of material the same total paying work cannot be performed in a given time, or, in other words, there is loss of power, which is the same thing as increased expense. *The limit of durability appears to be when the repairs equal the rate of interest of money, on the cost of the vehicles or permanent way.* Also since the durability has strict reference to the loads of freight and the velocity of trains, and the velocity is a destructive agent, taking effect equally through the freights and the vehicles for any given railway, and since the vehicles have ultimately to sustain the total destructive force of both, the durability will be greatest with the best form of vehicle, when the amount of material in it is limited to the amount of paying freight it is destined to carry.

It appears to the author that if these principles be kept in view the result will be that there will be neither waste of capital in trains or in way or works, and that the expense of the whole working will then be equally divided between the trains and the general management H (*c*, *d*), and these expenses will with ordinary skill in direction be found to be at their minimum while the line will be working at its maximum with greatest safety.

O. From what has been said it appears that railways must carry more cheaply the broader the gauge, provided there is full traffic for them in proportion to the square of the gauge, and that though it may be possible to execute the same amount of work on a double line of smaller gauge as on a single one of larger gauge, yet it cannot be done as cheaply per unit.

This seems to have been thoroughly understood by the great engineers who projected our first railways, and led to the adoption of gauges in in each case supposed to be suited to the probable traffic. But general commercial interests and considerations of public convenience have in most countries compelled the subserviency of the private interests of separate undertakings to the extent of the acceptance of a standard gauge. It is, therefore, no longer practicable to suit the gauge to the traffic in all cases, and an average has to be adopted. Where the single line of a standard gauge has not sufficient traffic, there will of course be some loss of net earning for which the gauge is not so much responsible as the projectors in overestimating the value of the traffic, or making the line at all. The consolation in such a case is, that the provision of railway communication in any locality has peculiarly remarkable effects in causing traffic to grow, and it may only be a matter of time to bring the line into full work; while, on the other hand, it seems that, if we cannot suit the gauge to an exceedingly flourishing traffic, we can at least restrict the amount of it to any one line of rails and other appliances, and by judicious proportionate extensions on capital account can perhaps improve our dividends.

The proportions maintainable in a railway are as unique as the parts of an engine, or a girder of a bridge. What would be said of an engineer who proposed to get increased power from a locomotive by putting additional cylinders to it without increasing the size of the boiler or any other parts?

The best design for a railway, like for other things, may be a matter of opinion, and is open to the test of practice. The success or otherwise will be proved by *efficiency* and *sufficiency*, which certainly do not contemplate the inclusion of accidents from failure of design, or the attempt to exact infallibility from human skill and agency in the working to make up for insufficient or ill-advised capital outlay.

Efficiency and sufficiency can both be tested to a great extent by the figures which should be obtainable from the accounts branch.

Requisitions for increased accommodation should always be tested by them, and very often accountants will be able to indicate in which direction economy can be attained, sometimes by additional capital outlay. It seems clear that with proper information as a guide, the working expenses need never exceed the interest of the capital used in construction per unit of work done, and that the least total cost per unit will then be attained with the maximum safe quantity of traffic, tending independent of the question of rates charged to the maximum dividend.

P. Modern practice proceeds to throw all our capital into heavy rails, heavy engines, and light wagons carrying heavy loads at the expense of durability, while the gauge has remained the same; it seems to be forgotten that the road, embankments, cuttings and bridges, are the most durable components of the whole machinery, affording by far the cheapest portion of the whole power of the railway, on that account.

It is impossible, within the limits of short paper, to illustrate diffusely, but the truth will be self-evident in the case of a reduction of a gradient from 1 in 150 to 1 in 300 by which the useful effect of the engines is at once doubled, and a great saving effected in the working of a steep gradient. Here, without any increase in the engine stock, additional power is gained, with no more expense for engines or repairs for them, while the repairs of engines per unit of paying work must be reduced. It is merely a question of the amount of useful work to be done, to determine the amount of capital it would pay to expend in flattening gradients, showing that both gradients and engine power should bear a proportion to the whole work to be done by the railway.

In fact it is only by a careful proportioning of all the parts to the whole work, and one another, that a railway can work best and cheapest; first, by ensuring safety and regularity, through a *sufficiency* of the mechanical contrivances, and secondly, by transferring the greatest amount of the power to be gained through those contrivances as a whole, from the most perishable to the least perishable materials composing the whole, or from the permanent way and rolling stock to the earthworks and roadway. Hence every gauge should have its respective gradients, curves, &c., in due proportion, and the cost of every component of a railway will bear a constant relation to the whole cost in all similar constructions to produce the best effect.

The determination of these proportions cannot be entered into here; the author has touched on the subject in his Notes on Railways, and thinks there are good grounds for adopting one-tenth the whole cost for stations, rolling stock, rails, and sleepers and fastenings in each case, making 40 per cent. of the whole cost over ordinary undulating country such as would represent the average of the railways of most countries, but the question requires a separate notice.

Q. This paper cannot be concluded without a further reference to the cost of carrying the units of traffic. It is well known that hardly a single company knows what it really costs to carry a unit of traffic. The management of the line is in the hands of departments, without a "head centre" of all continually testing the efficiency of every link in the chain.

The traffic department arranges cunningly-designed tables at high fares, with occasional cheap excursions at times when one would think that the increased numbers in pursuit of pleasure would be more profitable to the railway at the ordinary fares. It need have but a passing regard for the cost of trains and possible smashes. The locomotive and carriage department is concerned in maintaining the capital stock without dictating to the management the number or size of the trains which should be run to keep down the repairs and renewals. The engineers have to keep the permanent way in order for an ever-increasing number of trains with which the capital appliances are perhaps not allowed to keep pace. In the face of the pressure for high dividends, founded on a misconception of the mode in which they can be best obtained, the representations of the engineers are often disregarded.

The directors, it is needless to add, are composed generally of persons more skilled in the combinations which go to make up the financial and commercial operations of companies than those relating to the mechanical working.

But there is a department which, hitherto having been kept exceedingly in the back ground, has nevertheless within itself the only keys to the mystery of economical working as a whole, and which in supplying an exact measure of the force expended, whatever its nature, reduced to a uniform standard, that of money, is without equal, as a guide to practice.

Much as may be said of experience in construction, it, after all, is only an element, the value of which can be weighed in each case by the result of the working, and without an accurate system of record of expenditure little or nothing can be known as regards economy in this respect.

The long neglected department of accounts and statistics has, in India, been put on an advanced footing which has already led to improved results. Not only should the accounts, however, be the medium of leading to the declaration of a dividend, but they should also contain such a record of expenses and work done, that all the intermediate steps by which the dividend is arrived at may be recognisable and measurable by the mechanical work done.

Just in the same way as the parts of a machine are porportioned to one another and the whole work for the best effect, so will the expenses of working and maintaining them be in proportion to the cost, if proper durability has been ensured. It ought to be in the power of the heads of departments to weigh the work they perform against the expense they incur, and a correct record of the work done being a *sine quâ non* for all purposes, steps should be taken to ensure its registration.

Hardly a single English railway can point out the expenses of working in detail or in the gross of a ton over one mile. They are absolutely in the dark as to the expenses they are incurring. Notwithstanding, however, the general absence of effort to obtain a correct register of the ton mileage, some managers having a lurking satisfaction in attaining, as near as possible, to some true standard, adopt various methods of approximating to one, sometimes by the train mile, and sometimes by the ton mile. They take the whole number of train or ton miles performed, and divide the whole expense of working thereby, thus getting out a train or ton mile rate.

Since it has been shown that the cost of carrying units of traffic depends largely on the number offering and the appliances available, it is clear that such a deduced rate must be exceedingly fallacious as a guide to the best paying rates.

Suppose a newly started omnibus to have only one passenger in it the first day, the proprietor might just as reasonably proceed to fix a rate for the next day for a single passenger which would pay the whole expenses of the omnibus.

No more can be charged to individuals, with prospect of success to the enterprise, than the proportion of the whole accommodation each individual avails himself of, and it is the business of the capitalist to provide no more total machinery than will suffice for the demand of the total number of individuals expected to use it.

R. It is evident, therefore, that the cost of carriage can be predicted correctly only with reference to a fixed quantity of traffic for every line and only in one way. But with accurate registers of the work done over similar sections of lines in ton mileage, a test would be kept up of the *efficiency* and *sufficiency* of the machinery, as well as the economy of departments, which would lead to the detection of causes operating to increase the working expenses per unit, either through fluctuation of traffic, or wages, or anything else to the detriment of the dividends, and would sometimes lead to suggestions which would, perhaps, tend to increase them.

S. As regards the proportion the whole rate should bear to the working cost per unit, we have seen that the cost per unit, including working expense and interest on cost of construction, will be least when the one equals the other, and consequently, if only the ordinary interest of money is sought in the way of dividend, as must be best for the public under a system of State railways, we have only to double the working expense per unit when the line is in proper full work, for the rate to be charged the public.

We can see, further, that to charge less than this per unit, on the one hand, will prevent the full interest on the capital being earned without an undue stress on the line to make up by numbers for too small a rate, which stress, in itself, will be a cause of extra working expense per unit, while, if we make it more than this, on the other hand, we shall not extend our inducements in the way of low fares to as large a body of the population with small incomes as we otherwise should; and as the number of persons with small incomes increases in an exceedingly large ratio from the richest as we go down to the poorest, there is every reason to diminish the fares as long as the number of persons using the line is increased in a higher ratio, till we get full work for our railway; we have more chance of doing this effectually the lower we go. The limit, however, is evidently when the interest is just being earned on every unit carried at least, expense, and this seems to mean when interest and working expenses are equal per unit.

T. Referring now to paragraph G, in which the question of rates was eliminated from the definition of the economical capability of the works, it will be noticed that we have arrived at the conclusion that the least cost is being incurred when working expense equals the interest of money.

Now, if we re-introduce the element of the rates, when these are subject to complete and unrestricted competition, there is no doubt but that the net earnings will prove, under circumstances most favorable to economical working, to be no more than will represent the interest of money at the market rate for good security, and the rates will be at a minimum but if monopolies enable higher rates to be sustained, the question of increased working cost will be held subordinate to the question of augmented receipts from increased quantities at high rates, and larger dividends may perhaps be derived from an overtaxed line, with a high working cost per unit, resulting from the employment of too small a scale of mechanical appliances, and it will depend on the relative increment of receipts and expenses per unit, how much the working expenses may exceed the market rate of interest with best effect.

But though a large demand on a line holding a practical monopoly may enable large gross receipts to be earned, with a comparatively small capital outlay, yet if that capital is not sufficient to provide proper facilities for doing the work, the result will be almost sure to be accident, delay, loss of time, and increased expense per unit of work done, which cannot be got over anyhow. But, admitting the legitimacy of these in any case, there will be the least capital employed with fewest accidents, largest traffic and gross receipts with smallest working expenses per unit, and consequently the largest dividends, when the traffic is limited to such a quantity that the expenses are equal, not to the current rate of interest, but to the net earning of the railway, or when the net earnings are 50 per cent. of the receipts.

U. It will, however, be very evident that the idea of increasing the dividends at the risk of life and limb, is no more justifiable in the case of railways than it is in the case of ships. The maximum of safety can only be attained by limiting the traffic to the proper capacity of the line, a state of things carrying with it also, as has been shown, the advantages of the least cost in working.

Railway travelling need apparently be attended with little more risk than any other mode of locomotion with proper appliances, and it seems very clear, that with fair treatment, railways, which must from the very arteries and veins of the country itself, must always be the most enduring investments procurable, leading to the fullest rate of interest obtainable anywhere on good security.

V. It will have been observed that the actual quantity of traffic most suitable to any given railway has not been stated, but if what has been written above is correct, it cannot be difficult to assign positive values for proportional ones.

Assuming the proportions of expenses under paragraph H (*c*, *d*,) to be the best, and that working expenses should not be more than the interest on the capital cost, we get at once one-fifth of that expense for fuel, by which the gross work to be done can be accurately gauged. The quantity required for hauling a ton over one mile can be easily ascertained from the section, and, with coal at a given price, the total quantity which should be consumed is known. Dividing the total consumption by the quantity required for a ton over one mile, will give the total number of tons to be hauled over one mile within the year with best effect.

Whether this amount of work would prove the least expensive per unit or not, owing to the abnormal state of prices (which, however, all more or less remain somewhat constant in proportion and fluctuate in actual value, with the rise and fall of wages and the interest of money) can only be tested by accurate registers being kept of the number of mechanical units of work done. The most accurate unit of measure is undoubtedly the ton over one mile, the whole force required for performing which will be made up of all the items of expense appearing in the working revenue account, the details of which will all bear a more constant proportion to the whole expense and to one another, reckoned on the ton mile, than by any other standard.

T. F. D.

No. CCXVI.

IRON BRIDGES FOR DEEP RIVERS IN ALLUVIAL FORMATIONS.

[*Vide* Plates V., VI. and VII.].

BY MAJOR T. F. DOWDEN, R.E., *Assoc. Inst. C.E.*

ON THE SPANS OF BRIDGES.

GENERALLY the cheapest efficient bridge will be the one having at every point the longest efficient span which can be made for a sum equal to the cost of the pier on which it rests.

It is not always possible to choose the span for a bridge. Circumstances may determine the span which alone is practicable, as when foundations can only be met with at particular spots, where certain breadths of span are required for navigation or other purposes, &c.

Where a choice of span can be made, it is evident that the cheapest efficient one is the most desirable, and that it cannot be attained without attention to the condition laid down above, to start with. It embraces a consideration of the whole of the circumstances which affect the cost of construction of any part of the bridge.

The cost per foot of waterway of the bridge for the pier, is as the length of the span inversely and the mass of the pier directly. The mass of the pier must, however, be increased somewhat for a larger span, to sustain the weight of the span and the load on it, so that the span cannot be increased indefinitely to reduce the cost of the pier per foot of waterway.

Also the cost per foot of waterway for the span alone in iron bridges increases in a ratio in excess of the span, rather owing to the material of which the bridge itself is made, than the useful load it is to accommodate: a remark that applies with greater force to the larger spans.

Hence there is no advantage in increasing the size of the span beyond what is required to reduce the cost per foot of waterway for an efficient pier to a minimum, so that the cost of both *pier* and *span* per foot of waterway may *unitedly* also be a minimum. The framing of a design in which the balance of efficiency shall be kept between the pier and the span must, therefore, be tentative in the first instance, for it is necessary to assume some breadth for the pier which it is supposed may be efficient for a given set of circumstances, as regards the force of the floods, nature of the foundation, &c., and from such a pier to deduce the longest efficient span which can be made at a like cost. It is not improbable that the breadth of pier assumed may require modification when this is done. It may be considered too large for the deduced span, in which case a reduction can be made, and from the reduced pier a new span may be deduced, and the process repeated till we have attained a design which is fully efficient, and which will at the same time afford the smallest span, and, consequently, cheapest bridge.

It may perhaps be simplest to take an example to show that the cheapest bridge will be, when the cost per foot of waterway as so adjusted for the pier, equals the cost per foot for the span.

Suppose a pier designed to suit a single line of railway over a given river, and fully efficient to withstand the forces in the river, &c., to cost £2,000, and the largest efficient span which can be made for a similar sum to be 120 feet. The cost per foot of waterway of pier and span will be $\frac{2000}{120} = £16{\cdot}66$ for each, or £33·32 per foot for both.

If a less span is used, say 60 feet, no saving can be effected in the pier, which is already supposed to be at a minimum to withstand the forces in the river. The cost per foot of waterway for the *pier* will be increased to £33·32 a foot. The cost per foot of *span*, if taken to vary as the span, which is true approximately up to 200 feet, will for 60 feet be £8·33 per foot. The total cost per foot of waterway of the whole bridge will then be—

Pier, ...	£33·32
Span, ...	8·33
	£41·65 for a bridge of 60 feet span.
Against, ...	£33·32 ,, ,, 120 feet ,,

Similarly it may be shown that a bridge of more than 120 feet span will cost more per foot of waterway.

Suppose we assume 200 feet for the span.

Then the pier will cost $\frac{2000}{200} = £10$ per foot of waterway at least, assuming that no increase to its mass is required for the increased span, which is somewhat improbable.

Also the cost of the span will be as the span per foot, or $\frac{200}{120}$ feet = 1·666 times as great.

The cost of the span will then be £16·66 × 1·666 =	£27·75
Add cost of pier, ...	10·00
Cost per foot of bridge, total, ...	£37·75 for 200 ft.
Against ...	£33·32 for 120 ft.

However the figures may be experimented upon, it will be seen that no other span than 120 feet, which, under the circumstances, can be made for a cost equal to the cost of the pier, will give as cheap a bridge.

From the proposition with which we started, it is now easy to see how it is impossible to avail ourselves to the full extent of any of the circumstances which tend to cheapen the construction of bridges, without allowing them to exercise their influence through the adjustment of the span.

Summing up a few of the leading points for the sake of brevity, it is evident from that proposition, that the following tend to economy in the bridge by shortening the span:—

(1). Good foundations, necessitating less expense for efficient piers.

(2). Small height of the piers reducing the quantity of masonry or material in the piers.

(3). Cheapness of the material of which the piers are composed.

(4). Greater strength of the material in the piers, reducing the quantity required.

(5). Cheapness of labour in constructing the pier.

(6). Any modification of design which gives the same efficiency with a less quantity of material in the piers.

Because any of these reduce the sum for which an efficient pier can be made.

The following tend to economy in the bridge by lengthening the span:—

(1). Excellence and strength of material in the span, rendering the unit strains per square inch higher, and spreading a given amount of material over a wider span.

(2). Cheapness of the material in the span, enabling a larger quantity to be used for a given expenditure in providing a larger span.

(3). Cheapness of erection or labour in elevating the span.

(4). Any modification of the design of the span by which an increased efficient span can be got out of a given quantity of material.

Because any of them tend to an efficient span of greater length for a given sum of money.

The work which a bridge has to do is referable primarily to the useful loads it has to carry, and the inertia it has to oppose to the stream it is constructed to cross. The cost of a bridge per unit of useful load increases as the span. It does not, however, necessarily increase in cost per unit of discharge in different rivers. Larger spans are not only more suited to larger rivers generally, as regards efficiency, but they are also necessitated on the score of economy, through the influence exercised, either by the height or depth of the foundations, on the cost of the piers.

As regards the efficiency of a design, it appears, that for deep rivers the *piers* should consist of a single member, and not of an assemblage of parts. The vibration which takes place even in piers consisting only of two large and lofty cylindrical members, renders the reduction of the speed of trains a serious element in the calculation of the relative efficiency of various forms of piers.

If double line bridges are to be resorted to only when the limits of single line bridges are reached, it is evident that the limit will be much sooner reached with a slow, than with a quick speed of trains, for no two trains can occupy the line clear lengths at the same time, and the reduction of speed over bridges is so much reduction of power of the single line.

The usual form given to masonry *piers* has undoubtedly a superior strength over all others, combining greatest solidity with greatest rigidity and stability to resist the action of the forces in the river, and the vibration caused by heavy rolling loads on the bridge. Besides this, the form admits of the greatest area of base for greatest resistance to the flood. It does away with the necessity for external connections in iron structures, which are a source of weakness and expense in maintenance. Obstacles such as trees are not liable to be arrested by cross currents and eddies between the members, as in the case of detached piles.

In the matter of the superstructure, it is evident that the character of the design must depend on the span to be used.

Where the rivers are large and the traffic is small, the total work in building the bridge will be more due to the size of the river than the quantity of traffic. The cost of efficient piers to suit both, as it has been shown, will indicate the span to be used.

In similar piers for similar circumstances, the cost would vary as the cube of similar dimensions, and the cost of spans up to 200 feet is as the square of the span. The cost of piers would therefore be as the cube of their height, and as the cost of the efficient span to suit, should be the same as that of the pier on which it rests, the cost of the span should be as the cube root of the height. Then since the spans are as the square roots of the cost, the spans should be as the square root of the cube of the heights of the piers from foundation to girder bed. This will give an approximate span for any river.

Thus if a 200 feet span costs £10,000, with pier complete, for a height of 85 feet from foundation to girder bed, a height of 60 feet would give—

$$200 \times \sqrt{\frac{60^3}{85^3}} = 200 \sqrt{\frac{1}{2 \cdot 83}} =$$

$$200 \sqrt{\cdot 353} = 200 \times \cdot 595 = 119 \cdot 0 \text{ feet for the span.}$$

The cost would also be as h^3, or £10,000 × ·353 = £3,530, and the cost per foot of waterway, $\frac{£3530}{119 \text{ ft.}}$ = £29·7 a foot, which is as $\frac{h^3}{\sqrt{h^3}}$ or $\sqrt{h^3}$.

The piers would not perhaps be quite similar for a constant breadth of roadway over the bridge; but it is evident that the circumstances necessitating a certain length of pier to resist the floods and area of base to support the weights, will often afford space for a double line at no increase of cost in large rivers, and to that extent there is economy in double over single lines in bridges over large rivers.

If the fall be assumed as constant, the velocity of the current varies as the square root of the hydraulic mean depth.

The discharge at any point of a river is as the depth multiplied by the velocity. For any given point the depth is the same as the hydraulic mean depth. If h represent this depth, the discharge at any point is therefore as $h\sqrt{h}$.

This same expression, however, represents the cost per foot of bridges for given total heights h; for $\sqrt{h^3} = h\sqrt{h}$. In similar circumstances, therefore, where the water level is at a given proportionate part of the pier in height, the ratio of the cost of various spans (up to 200 feet) is as the discharge of the river per foot of waterway.

The waterway is obstructed by piers in proportion to their breadth b (which dimension, however, varies only as the cube root of the masses in similar constructions), while the span should vary, as has been shown, as the square root of the cube of any similar dimension, and consequently as $\sqrt{b^3}$. The obstruction from piers per foot of waterway will then be as $\frac{b}{\sqrt{b^3}}$ or as $\frac{1}{\sqrt{b}}$ which is inversely as the square root of the breadth, and consequently the total obstruction is less in larger bridges from the piers, although the piers are individually larger. If the piers in two different spans were as 4 to 9 in breadth, the obstruction would be as $\frac{1}{\sqrt{4}}$ to $\frac{1}{\sqrt{9}}$ or as $\frac{1}{2}$ to $\frac{1}{3}$.

From this it seems that the larger spans used for larger rivers are more suitable and efficient, for while they can certainly, up to 200 feet be made at a cost proportionate to the discharge of the river, the area of discharge is less contracted the larger the span is made.

The Bombay, Baroda, and Central India Railway Bridges.

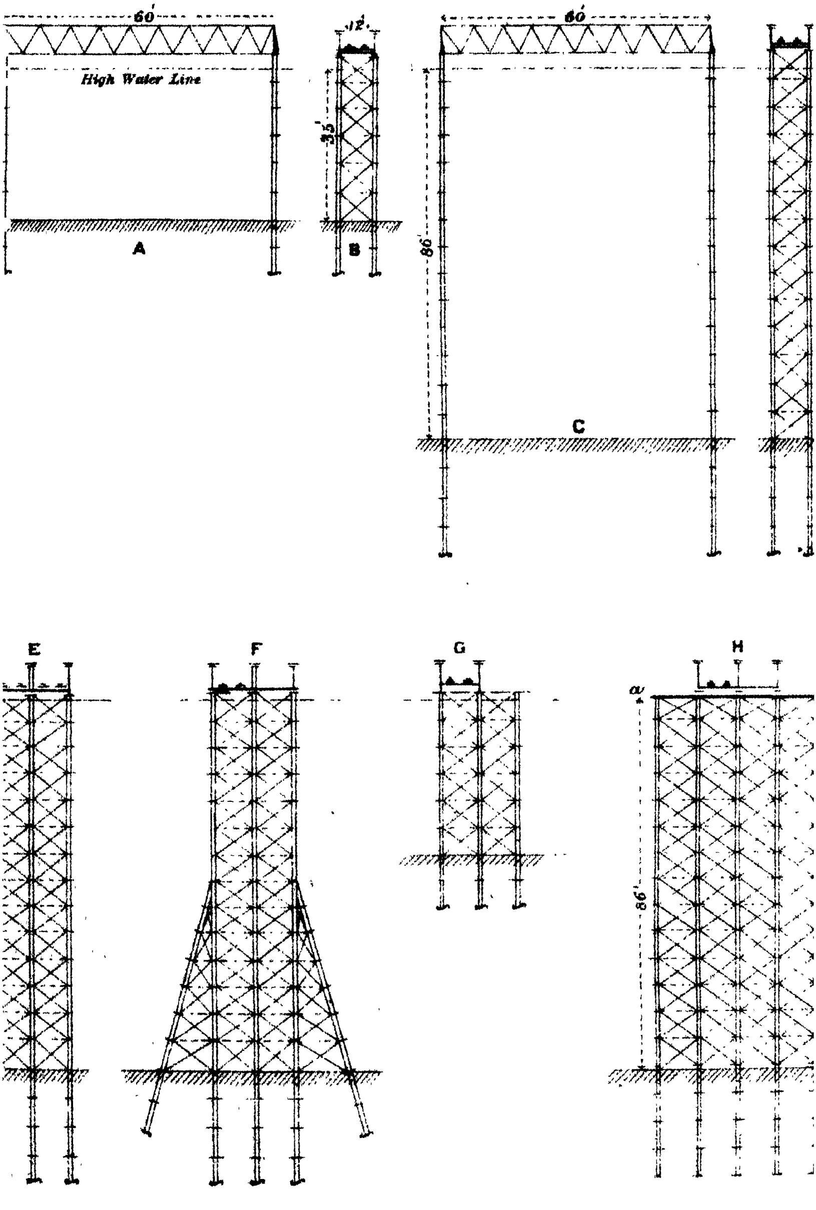
If all that has been written above is correct, the fallacy of attempting to apply the same span to rivers of different sizes will have been apparent. It is believed that the primary object aimed at in providing a uniform description of material for the bridges on the Bombay, Baroda, and Central India Railway, was to prevent the confusion which might have arisen in sending out and erecting the ironwork. The advantage of this was undoubted in the direction of simplifying the stores operations, but unfortunately the primary importance of the suitability to the purposes for which the material was to be used in all cases was not to be disposed of in such a general way.

The formation of the ground over which most of the Bombay, Baroda, and Central India Railway is constructed, is that which results from the decomposition of the material of which the western ranges of mountains of the Indian Peninsula are composed, and of the delta formation which has been deposited in its place by the action of the numerous rivers and streamlets coming from the interior. It is hardly possible to point to any spot, except where the original formation of trap is met with in a few places, which is not still liable to flood from the hills. It is true these floods occur only once in many years in some localities, yet when the nature of the formation is considered, it is impossible to concede that the action which produced it has ceased in any part permanently; for it is only a matter of time for the accumulation of soil to assume such proportions in any district at the present time liable to flood, for the waters to be in consequence diverted into others at a lower level.

This circumstance leaves it difficult to decide the probable highest flood line, but it is very certain that it may often be assumed at considerably above any indication of defined banks. Former generations have doubtless placed their towns on the spots, least liable to inundation, yet we now often hear of these towns being almost washed away. Ahmedabad and Surat, the two largest towns on the line of railway, have been inundated more than once in the writer's memory. If the height of the floods is difficult to determine, how much more must be the nature of the soil for foundations. Countless ages have elapsed while the formation, as described has been going on. Doubtless, it may be predicted with some certainty, that coarser material will be met with nearer the mountains and the deeper we excavate in any locality.

This is borne out by practice, but any endeavour to reach the original formation is in most cases useless. Sometimes conglomerate may be met with of extremely recent character, and of no great thickness; but it has often served, like detached beds of clay, no other purpose but to impede the operation of screwing down the piles for the piers, without being substantial or extensive enough to form a safe foundation. But if the nature of the geological formation, which leads us to expect to meet with little solidity at a practicable depth, leads to doubts and uncertainties on the one hand, it also leads us to assume this amount of certainty on the other, viz., that the action of all the river beds, taken together, must be one causing them generally to silt up rather than to scour, and if we can

IRON BRIDGES FOR DEEP RIVERS IN ALLUVIAL FORMATIONS.



attain a depth of foundation which is likely to be safe from any local changes and make proper provision for the highest possible floods, we may expect permanency, for many scores of years, in the structures to be erected on it.

The foundations of the pile bridges on the Bombay, Baroda, and Central India Railway are mostly in the river silt. The piers are screwed down to a depth deemed sufficient according to the degree of power required in screwing, and the general appearance of the section of the river. It is evident that the only hold the piles* have, is by friction against the surrounding soil, and a certain direct bearing on the screw to sustain the weigh of the bridge, or the loads on it; and to prevent being pulled out, there is the screw acting like a mooring.

Now *Figs.* A, B, *Plate* V., give a general idea of the design which, for a 60 feet span, would perhaps be found best to suit a flood of 35 feet in depth, and making the cost of the superstructure equal to the cost of the spans.

Supposing this the case, compare it with *Figs.* C, D, where the height of depth of the river is 86 feet or more.

In the latter figures we have, perhaps, all that is required in the matter of supporting the rolling load, but the load on the foundations of an immense height of pier renders it necessary to provide increased thickness and weight in all the material, which could not be required if bridges only of the size shown in *Figs.* A and B were to be built. Besides that, there is a pressure of flowing water against the piers, *Fig.* B, which at the same velocity would be as 86 to 35, while the leverage against the surface of the river bed would be also in the same proportion, making the effort of the piers to overturn as the square of those numbers, *i. e.*, as 74 to 13. If the braces acted so as to make the two piles like a single girder, since the breadth is the same in both cases, the leverage would be as above 74 to 13. The bracing, however, does not act so as to consolidate the two piles into one rigid member, but affords a peculiar facility to brushwood to collect in it. The piles, without a rigid connection, vibrate in proportion to their length very considerably, and in the absence of mutual support, depend wholly for maintaining their position on the tenacity of the bolts or other appliances for connecting the joints of the piers. The vibration is counteracted to some extent by the weights of

* 2 feet 6 inches external diameter.

the girders and superstructure where they rest on the piles direct, but it is impossible in a pier composed of a great number of members to prevent vibration of the parts *inter se*. This vibration is communicated to the soil of the foundations. It is in extent evidently as the square of the height of the pier or the flood. We all know how we should proceed to pull a stake out of the ground. We should wriggle it about and enlarge the size of the hole most at the surface of the ground, diminishing towards the lowest end of the stick till we could lift it out perhaps with the little finger. We know, too, that we should have much less difficulty the longer the length of the stake out of ground and the less the length in the ground. The vibration has a similar effect; it loosens the soil and the rushing water carries it away perhaps. Anyhow, it seems that for the piers to have equal stiffness in the soil, they should be sunk to a depth corresponding with the height above ground, and to exercise a proportionate resistance to the effort of the river should have a diameter in proportion. But as the size of the cylinders in this uniform material is all the same, this could not be done, and the case has been met by putting in more piles and connecting them as rigidly as possible with the others. It was found that in comparatively small bridges this extra pier was required; but it was accompanied with the obvious disadvantage of increased total vibration. To remedy this, various systems of ties were applied to steady the extra member in the pier, but without success, and it was then thought desirable to erect the additional girders, though the traffic required only one roadway, to give steadiness to the additional pile (*Fig.* E). The element of steadiness gained from the spans had then been doubled over that in *Fig.* B, while the element of unsteadiness and vibration from the piers had been only increased 50 per cent. Some improvement, therefore, was gained on the whole, at a sacrifice of material not required for traffic purposes. But even then it was found that in high bridges the strength was not sufficient, and, mistaking the piers for single rigid bodies instead of an assemblage of vibrating parts, attempts were made to strut the piers as in *Fig.* F. It was then found that these piles added very largely to the vibration; they could also not so easily be screwed down, and if not put as deep as the main piles, they introduced elements of risk from washing out.

The last improvement was to erect the fourth and fifth piles vertically (*Fig.* H), thus still further largely increasing the area of the pier and braces exposed to the accumulation of brushwood and the force of the water, and also increasing the total vibration. Finally, two cross-girders, *a b*, were introduced under the 60 feet spans, which being rigidly attached to the piers have had some effect in counteracting some of the vibration.*

These cross-girders have also been used with a view of guarding against settlement in any of the piers where the foundations are not considered very good. These cases are most frequent in the Nerbudda, Bessein, and Viturnee river bridges. It will be found, it is believed, on reference to the construction diagrams of those bridges, that the depth of the piers in the ground is not in all cases proportioned to the height of them above ground. They have not, therefore, the same degree of stability to resist overturning. But it will be noticed that since the appliances for connecting the joints of the piers are limited to a uniform system, there is danger of failure at the joints just above ground with too great a height of pier, irrespective of the question of leverage in the soil. This failure has occurred more than once. The danger to these bridges, with a side set of the current, is very great; it is not decreased by the vast area of piles and bracing, or by the fact that the light girders of the superstructure are, as usual, merely laid on, without being rigidly fixed to the piers, to allow for expansion and contraction. The failures which have occurred to the large bridges on the Bombay, Baroda, and Central India Railway, have very greatly increased the working expenses, and there is no knowing where this state of things is to stop. In addition to this it is necessary to maintain these structures. The chief part of the expense of maintenance consists in employing divers constantly to inspect and renew the bolts, bracings, and fastenings below water.

Owing to some galvanic or chemical action which takes place between the cast-iron of the piles and the wrought-iron of the bolts, nuts, and the braces, these connections do not ordinarily last longer than about three years. They dissolve away, laminate, and change their nature, lose their high specific gravity, and become more like plumbago than anything else. The expense of maintenance, therefore, has increased in exact proportion to the amount of pile work.

It is not known what the average height of the piers in the largest

* The author, some years ago, passed over the Nerbudda Bridge on foot a few hours before several spans were washed away. The vibration then going on was sufficient to induce a considerable acceleration of pace in all present.

rivers, including the foundations, is, but it is probably not less than shown in *Fig.* H. In 1871 the cost of the whole of the bridges had been about a million sterling, while the whole construction capital of the line was then only about six millions for about 310 miles. Since then, large additions have been made to the bridges, and some reconstructions have been carried out. The Nerbudda bridge alone is some 3,600 feet long, and it is probable that the long bridges, if all put together, would reach over three miles.

It may be as well now to give a comparative estimate of, say, the existing and a proposed bridge for the Nerbudda River.

Nerbudda Bridge.

List of the piers of the Nerbudda bridge, taken from page 258, Vol. 27, of the Proceedings of Institute of Civil Engineers.

No. of piles above the screw piece which appears as if in a clay stratum.

	No. of Pier.	No. of Piles.	No. of Pier.	No. of Piles.	No. of Pier.	No. of Piles.
South end	1	5	27	7	53	8
	2	5	28	7	54	8
	3	5	29	7	55	8
	4	5	30	7	56	8
	5	5	31	7	57	8
	6	5	32	7¼	58	8
	7	5½	33	7½	59	8
	8	5½	34	7¾	60	8
	9	5½	35	7¾	61	8
	10	5½	36	7½	62	7¾
	11	6	37	7½	63	7½
	12	6	38	7½	64	7½
	13	6½	39	7½	65	7
	14	6½	40	7½	66	6
	15	6¾	41	8	67	5¾
	16	7	42	8	68	5½
	17	7¼	43	8¼	69	5¼
	18	7½	44	8¼	70	5
	19	7½	45	8½	71	5
	20	7¾	46	8¾	72	5
	21	7½	47	8¾	73	5
	22	7½	48	9	74	5
	23	7½	49	9	75	3 Broach end (North).
	24	7½	50	9¼		
	25	7	51	8		
	26	7	52	8		

(Piers 1 to 15:) These spans not erected apparently.

No. of Piers.	No. of Piles.	Total No. of Piles.	No. of Piers.	No. of Piles.	Total No. of Piles.
1	3	3	4	7¾	31
5	5	25	13	8	104
1	5¼	5¼	2	8¼	16½
1	5½	5½	1	8½	8½
1	5¾	5¾	2	8¾	17½
1	6	6	2	9	18
9	7	63	1	9¼	9¼
1	7¼	7¼	—		——
15	7½	112½	60		Total 488

Average $= \frac{438}{60} = 7 \cdot 3$ piles $= 65 \cdot 7$ feet $=$ height of piers above the screw piece.

PROBABLE COST OF THE NERBUDDA BRIDGE, 60 FEET SPAN.

Warren girders, wrought-iron, at 18½ tons per span, ...	37 tons.
Cross girders, say, 10 tons per span, ...	20 „
Add transverse stiffening girders, say, ...	6 „
Total, ...	63 „

5 Rows of piles—

50 feet above ground, 1½ inch thick.
30 feet below,

80 feet, including screw.

Total weight—

$\frac{5 \times 26 \cdot 66 \text{ yards} \times 106 \text{ square inches} \times 1 \text{ lb.}}{224 \text{ lbs.}} =$ ... 62·7 tons.

Add ribs, bosses, joint flanges, &c., ⅕, ... 12·34 „

75·04

⊥ Bracings, 5 piles in height—

Horizontal, 10 × 14 feet = 140 feet.
Slant, 10 × 16 feet = 160

$\frac{300 \times 20 \text{ lbs.} = 2 \cdot 68 \text{ tons}}{4 \quad \text{spaces} =}$ ... ... 10·72 tons.

Bolts and nuts—

Pile 8 joints × 5 piles × 12 bolts = 480, at 2½ lbs., ... 1,200 lbs.

Brace bolts—

Horizontal,	20 × 5 × 100, at 3 lbs., ...	300 lbs.	
Slant,	20 × 5 × 100, at 3 „	300 „	
Middle of do.	20 × 5 × 25, at 2 „	50 „	
		1,850 „	= ·825 tons.

Summary.

	£
63 tons girders, at £24, ...	1,512
75 „ cast-iron piles, at £12 (including driving), ...	900
10·72 „ wrought bracing, at £14, ...	150
·825 „ bolts, &c., at £28, ...	23
1,600 cubic feet concrete, at £1 per hundred, ...	16
Total, ...	2,606
Contingencies, $\frac{1}{10}$, ...	260
	60)2,866
Cost per foot, ...	47·77

Proposed new Design.

Estimate of the cost of a Pier.

(*See Plate* VI.)

Excavation in mud and water—

For foundations by sinking of the caissons.

	No.	Length	Bdth.	Diam.	Total cub. ft.
▭ parts, ...	1	30	19	30	17,100
D parts,		$\frac{283 \cdot 5}{2}$		30	8,505
					25,605

Ironwork, cast—

	No.	Weight.	Total.
Foundation course, ...	1	9·5	9·50
Courses 18, 19, 20, ...	3	17·79	53·37
Course 17, ...	1	17·29	17·29
Courses 11—16, ...	6	14·72	88·32
Course 10, ...	1	14·35	14·35
Courses 2—9, ...	8	11·91	95·28
Course 1, ...	1	9·50	9·50
Total, ...			287·61
[illegible] Feathers &c. [illegible]			57·52
Grand Total,..			345·13 tons.

Iron bolts and nuts—

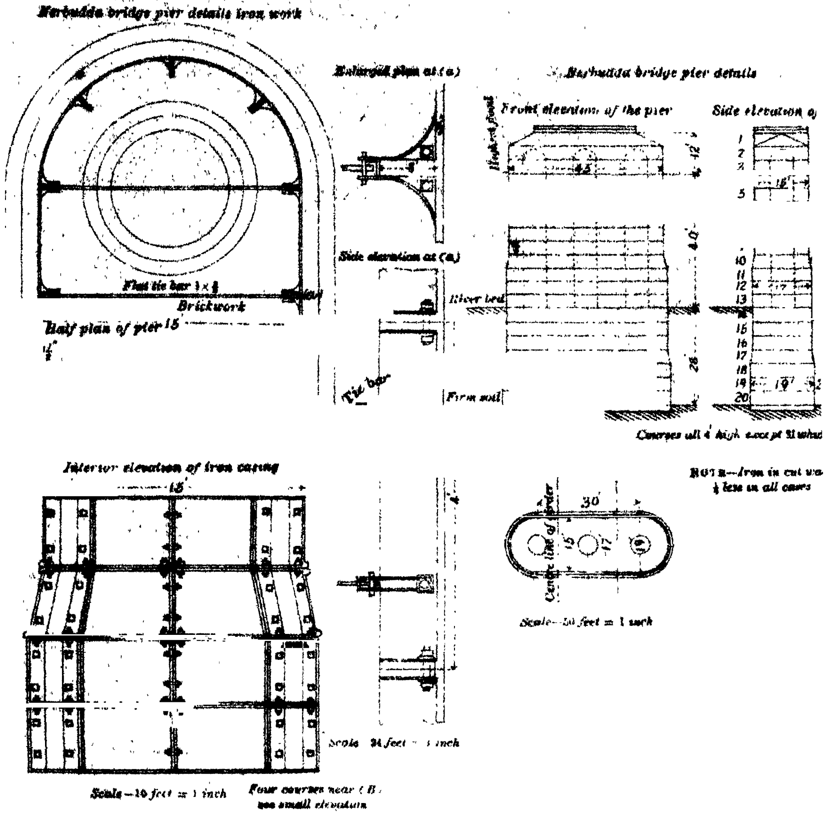
		No.	Lgth.	Diam.	Wt. each	lbs.
Vertical,	Bolts, ...	20 × 36	6″	1″	1·31 lbs.	943
	Nuts, hexagon,	40 × 36	6″	1″	1·10 „	1,584
Horizontal,	Bolts, ...	21 × 36	6″	1″	1·31 „	990
	Nuts, hexagon,	42 × 36	6″	1″	1·10 „	1,663
						5,180 lbs. = 2·81 tons.

Bar iron ties—

Above ground.

	No.	Length.	Diam.	Rg. ft.
Courses 11, 12, 13,	6 × 3	17	1″	306
Course 10, ...	7 × 1	16	1″	96
Courses 1—9, ...	6 × 9	15	1″	810
				1,212
Add for contingencies, $\frac{1}{10}$				121
Total, ...				1,333 at 2·62 lbs. = 1·56 ton.

IRON BRIDGES FOR DEEP RIVERS IN ALLUVIAL FORMATIONS.



QUANTITY (CAST IRON) IN EACH DESCRIPTION OF COURSE.

		No.	L.	B.	Thick	Sq. ft.	Total wt. lbs.
COURSES 2 to 9							
	Sides - -	2	30'	4	1½"	240·0	14,400
	Ends - -	2	23·5	4	1½"	188·0	9,400
	Flanges -	18	·66	4	1½"	48·	2,880
		Total					26,680 = 11·91 Tons
COURSES 11 to 16—							
	Sides -	2	30'	4	1¾"	240·0	16,800
	Ends - -	2	26·7	4	1¾"	213·6	12,816
	Flanges -	18	·66	4	1¾"	48	3,360
		Total					32,976 = 14·72 Tons
COURSES 18 to 20—							
	Sides - -	2	30	4	2"	240·0	19,200
	Ends - -	2	30	4	1¾"	240,0	16,800
	Flanges -	18	·66	4	2"	48·0	3,840
		Total					39,840 = 17·79 Tons
	Sides - -	2	30	4	1¾"	240	16,800
	Ends - -	2	25·	4	1¾"	200	12,000
	Flanges -	18	·66	4	1¾"	48	3,360
		Total					32,160 = 14·35 Tons
COURSE 17—							
	Sides - -	2	30	4	2"	240	19,200
	Ends - -	2	28·7	4	1¾"	230	16,100
	Flanges -	18	·66	4	2"	48	3,840
		Total					39,740 = 17·30 Tons
COURSE 21—							
	Sides - -	2	30	2	4"	120	19,200
	Ends - -	2	30	2	4"	120	19,200
	Flanges -	18	·66	2	4"	24	2,880
		Total					41,280 = 18·43 Tons
COURSE 1—							
	Sides - -	2	30	4	1½"	240	14,400

Filling in the pier with concrete—

Same as excavation in soil and water, .. 25,605 cubic feet.

Brick masonry above ground—

		No.	Length.	Breadth.	Height.	Cubic ft.
Course 11, 12, 13,	Middle, ..	1	30	17	12	6,120
	Ends, ..	2	$\frac{226}{2}$		12	2,712
" 10, ..	Middle, ..	1	30	16	4	1,920
	Ends, ..	2	$\frac{201}{2}$		4	804
" 2 to 9, ..	Middle, ..	1	30	15	32	14,400
	Ends, ..	2	$\frac{176 \cdot 7}{2}$		32	5,674
" 1, ..	Middle, ..	1	30	15	4	1,800
	Conical Ends,	1	176·7		$\frac{4}{3}$	234
						33,644
Deduct wells, 7 feet diam., ..		3	38·48		52	6,002
			Total cubic feet,		..	27,642

Abstract of cost—

		£
Excavation and sinking of piers in mud and water, ...	25,605 c. ft., at £1 per 100 c. ft.,	256
Cast-iron work (including erection),	345 tons, at £10·23 per ton, ..	4,140
Iron bolts and nuts, ...	2·31 tons, at £28 per ton, ..	65
Bar iron, ..	1·56 tons, at £14 per ton,	22
Filling concrete, cement, or hydraulic lime mortar, ...	25,605 c. ft. at £1 per 100 c. ft.,	256
Brickwork in hydraulic lime mortar,	27,642 c. ft., at £2·5 " " ..	650
		4,829
	Contingencies, 5 per cent., ..	241
	Cost of pier. Grand Total, ..	5,070

In designing the pier for the bridge with an expensive material like iron for a casing, we require greatest solidity with least perimeter.

The solidity and area of foundation of the pier will be increased in a larger proportion than the increase in length of the perimeter as long as the breadth does not exceed what will give an equal length for the circular ends as for the sides of the piers. The actual length of the pier at top is determined by the breadth of the roadway, and is so adjusted that the main girders may rest centrally on the two halves of the piers. This places the load of the spans centrally on the area by which they are supported, and practically results in the average length of the piers being about double the breadth of roadway. This form of pier is stronger than would result from the employment of two detached cylinders of an average diameter of 17 feet and 1⅝ inch thickness, which would absorb about 306 tons of cast-iron. For deep rivers, where the floods have great force, the superiority of this stronger form is well worth 39 tons of additional cast-iron. By combining the length, breadth, and perimeter in the above way, with two offsets for plinth and foundation, the result is a superficial area of foundation of 853 square feet.

The weight on it is—

Piers—Iron, ..		348·87 tons.	
Concrete, ..		1,393·00 „	25,605 cub. ft., at 120 lbs. per ft.
Brickwork,		1,234·00 „	27,642 „ „ 100 „
Total Pier,		2,975·87	
Spans—Iron, ..	211		
Rolling load, ..	228		
Permanent way, &c.,	83		
Total span, ..	522		
Total piers and span,			3497·87 tons.

Pressure per square foot of foundation about 4·05 tons.

The pressure usually allowed, is understood to be from 4 to 8 tons, and the surface friction from 300 lbs. to ¼ ton. The latter would amount to a considerable relief of the pressure on the bottom area. Some idea of it may be formed by estimating the weight of the foundation below the river bed, in comparison with the weight of an equal bulk of the material of which the river bed is composed. It is not improbable that the difference would at least take off 1,048 tons from the downward pressure, allowing the specific gravity of the pier and river bed to be as 3 to 2. This, on a vertical surface of 3,495 square feet, would give ·286 tons per square foot, and take off 1·23 tons per square foot from the bottom pressure.

The caissons to be sunk in the usual manner by dredging out the silt from the interior. Should unforseen difficulties arise in the progress of this operation, recourse to be had to working in a *plenum*.

The piers to be built up to the level of the ground or high-water mark, according as the bed is dry or wet.

The spans then to be built in their places in the former case, and on pontoons in the latter, and floated into position.

The span to be lifted from the piers themselves as the construction of the piers proceeds, by hydraulic rams or screw jacks, till the full height is reached.

Spans.

To determine the span from the pier we have—

The cost of wrought-iron in girders, &c., at	£18	0	0	a ton.
Freight to India, ...	2	0	0	„
Carriage and erection, ...	4	0	0	„
Total,	£24	0	0	

The cost of the pier is to be £5,070, and this divided by £24 will give 211 tons of iron for the weight of the superstructure supporting the roadway.

This brings us now to the important question, to find the longest efficient span that can be erected for this weight of iron.

The subject of iron girders for bridges has been very carefully treated by Mr. Bindon B. Stoney, in a book of 614 pages in length, which, will well repay a careful perusal.* It is clear that when so much has to be said to convey a notion of the theoretical and practical details of iron girders, it would be out of place here to do more than touch on a few of the points which appear most to bear on the particular case in hand.

First then as regards the greatest broadth of the roadway, for a given quantity of iron it is evident that this will occur in a bridge with a single pair of main girders when the transverse girders collectively weigh no more or less than one of the main girders.

Next the greatest length of span of a girder must occur with a given quantity of iron when the depth bears such a proportion to the length that the quantity of iron in the connecting web will be one-third of the

* Longmans, Green & Co., London.

quantity in the whole girder. This proportion can, it seems, be maintained with a ratio of from $\frac{1}{12}$ to $\frac{1}{8}$ of the span according to the design.

The work the girder has to do is to support a permanent load, consisting of the roadway, sleepers, rails, &c., estimated for a single line at about ·54 tons per foot run, and a rolling load, of from 1·45 tons per foot run to ·75 tons, for spans between 40 feet and 400 feet.

Besides this there is the weight of the span itself.

Now, whatever the load may be taken per foot, both it and the permanent load of sleepers, rails, &c., may be considered as the *useful load*, as far as the question of span is concerned, and this load will require a certain quantity of iron to support it. If the load were constant per foot, the quantity would vary as the square of the span; because it will be as the linear dimensions multiplied by the strain, and if the strain is from weights reckoned on the foot of span, the total quantity of iron must be as the square of the span.

Also the weight of similar girders must be as the cubes of their similar dimensions, and consequently amongst them as the cube of the span.

Accordingly if the useful load increased in a constant ratio with the span, the weight of iron due to it would increase as the square, while the quantity due to the weight of the girder itself, would, for similar designs, increase at the same time as the cube of the span, or more rapidly.

As a fact, however, we find that the practical load for railways per foot run, decreases from a span of 40 feet to one of 400 feet, about one-half, owing to the distribution of the engine weights over a greater length of train in longer spans, and also that short bridges suffer more than long from a high velocity, and require some extra stiffening, so that in longer spans the material required for the useful load does not increase in as large a ratio as the square of the span, while in practice, modifications of design are made which by alteration of form allows of girders being made of less weight than is due to a ratio of the cube of the span. These modifications are the progression from plate to Warren girders, and from them to lattice, bowstring, and suspension girders, as the span is increased, by which the supports are more distributed, and rigidity of parts in compression preserved, or the use of iron in compression, avoided as much as possible, as in the last-named description of span.

Thus on the one hand, we have the total weight of the span depending on one element (the useful load) which decreases per foot run from small to larger bridges, while on the other hand there is another element (the weight of the bridge itself) which increases per foot of span.

Practice seems to show that the *total* quantity of iron required to meet both, taken together, is pretty constant up to a span of 200 feet, to which limit the quantity is, as nearly as possible, as the square of the span.

When this limit is passed, the weight of the girders becomes such a large element of the calculation, that the spans may cost anything, from the cube to the fifth power of the span.

As regards the limit of span in reference to the useful load only, it is evident that the greatest useful load will be accommodated with the least quantity of iron in the span when the total strain exercised by the useful load equals that proceeding from the weight of the span itself.

In a span for a single line of railway, this appears to be the case at a limit of about 200 feet. But we have already seen that this limit may be passed with a view of procuring the cheapest *bridge*, which cannot be estimated without including also the cost of *piers*. These may warrant the span being extended far beyond the paying limit with respect to the useful load only, according to the circumstances which affect the cost of them.

A simple rule is quoted by Mr. Bindon Stoney as Anderson's rule, for the weights of lattice and plate girders under 200 feet in length. It is this:

Multiply the total distributed load in tons by four, and the product is the weight of the main girders, end pillars, and cross bracing in lbs. per running foot.

Now the only disadvantage of this simple rule apparently is, that it requires you to guess at a great part of what you want to know.

The total distributed load of course includes the weight of the girders themselves. Mr. Bindon Stoney appears, in assuming his permanent span load, to have been guided by the cube of the span, where only a small difference of span occurs; but he tells us that a knowledge of the weights of spans beyond 200 feet is only to be gained by experience. As bridges of all practicable spans have been made, it is a pity that some concise record of their weights does not exist for the guidance of engineers.

But Mr. Bindon Stoney gives us a valuable little table of weights of girders up to 200 feet span, which is sufficient for our present purpose. An abstract of it is given below:—

Weights of Single Line wrought-iron Lattice Railway Girders in tons; depth being $\frac{1}{12}$ the length.

Remarks.	Span.	1 Ton.	1¼ Tons.	1½ Tons.
(*a*). Working strains 5	12	0·7	0·8	0·84
tons per square inch	16	1·14	1·36	1·44
for tension, and 4	24	2·19	2·59	2·73
tons for compres-	32	3·4	4·0	4·2
sion.	40	4·9	5·8	6·2
(*b*). Dead weight of cross	60	11·3	13·4	14·0
girders platform;	80	20·8	24·3	25·5
ballast sleepers	100	33·5	39·0	40·7
taken at ·54 tons per	120	49·7	57·6	60·2
foot run.	140	70·5	80·3	84·0
(*c*). Engines of 24, 30 and	160	95·4	108·2	112·6
32 tons giving stan-	180	125·4	141·6	146·7
dard load at 1, 1¼,	200	162·2	180·0	186·7
and 1½ tons per foot				
run of single line.				

The above gives the weight of main girders, end pillars, and cross bracing.

Not included—cross girders, ·18 tons per foot run (3 feet apart).

In regard to larger spans, the weight in some special examples are given as under:—

(Depth $\frac{1}{12}$ of the length).
(Single line).

			Tons.
400 feet,	„	„	1,154
480 „	„	„	2,586
600 „	„	„	3,886

N.B.—The weights of main girders for a double line bridge are double those given for a single line bridge, and of cross girders four times ·18 tons per foot run.

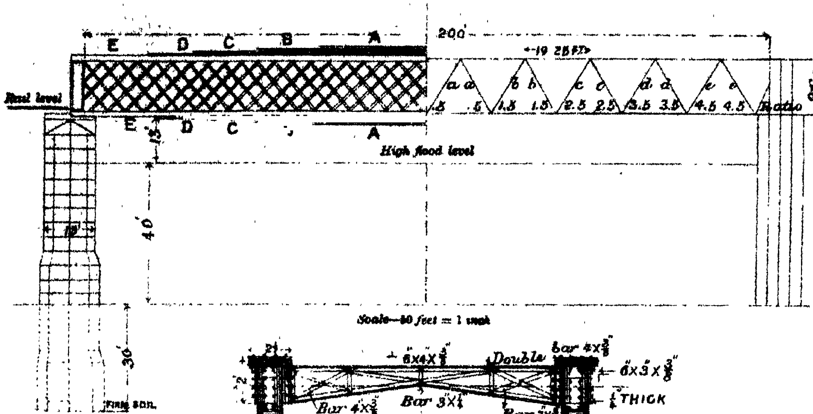
From this table it appears we may expect to be able to make a 200 feet span, with 212 tons of iron, viz.:—

Weight of girders, end pillars and cross-bracing, ...	186·7 tons.
Cross girders at ·18 tons per foot, ...	36·0 „
	222·7

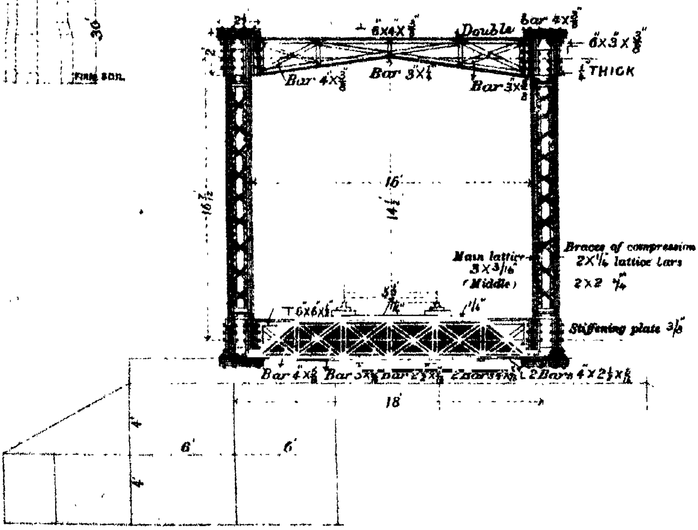
This is a little over the given quantity, but it is stated that the quantities in the higher spans of the table are perhaps rather in excess of truth.

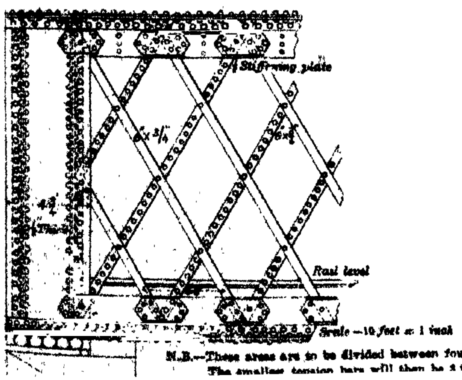
The total distributed load on a 200 feet span for all, is made up as below:—

IRON BRIDGES FOR DEEP RIVERS IN ALLUVIAL FORMATIONS.



Scale—40 feet = 1 inch





Scale—10 feet = 1 inch

WEIGHTS OF THE PARTS OF THE GIRDER IN TONS.

[ONE QUARTER SPAN]

Tension Bracing	Compression Bracing	Tension Flange	Compression Flange
a 0·11	a ·23	A 1·56	A 2·23
b 0·34	b ·67	B 2·65	B 3·02
c 0·57	c 1·12	C 2·62	C 2·41
d 0·79	d 1·57	D 2·00	D 1·79
e 1·02	e 2·01	E 1·14	E ·63
		F ·29	
		10·685	

THE SECTIONAL AREAS CORRESPONDING IN INCHES ARE GIVEN BELOW.

a 3·02	a 7·64	A 108·0	A 114
b 11·81	b 23·30	B 104·0	B 106
c 19·81	c 39·00	C 90·0	C 87
d 27·50	d 54·50	D 69·0	D 60
e 35·50	e 69·80	E 39·5	E 29
		F 10·2	

N.B.—These areas are to be divided between four double lattice bars in the web, which is to be double
The smallest tension bars will then be 3 in. by ·15 or about 3 in. by ¼ in. ...

Cross girder 8 feet apart, ...	·18	tons per foot run.
Sheeting 4 inch planks and bolts, ...	·10	" "
Rails, chairs, &c., ...	·06	" "
Ballast, ...	·20	" "
	·54	
·54 tons × 200 feet, ...	108·0	tons.
Rolling load 1·14 tons, ...	228·0	"
Girders, &c., ...	186·0	"
Total, ...	522·0	"

Weight of girders, end pillars and cross-bracing by Anderson's rule:—

$$\frac{522 \text{ tons} \times 4 \times 200}{2,240} = 186 \text{ tons.}$$

With 522 tons of total distributed load, we can now start to apportion the whole quantity of iron between the different parts of the girder.

The proposed angle of bracing is 30° with the vertical, making a series of equilateral triangles. This does not give the least quantity of iron in the bracing, but it admits of the bars composing it being in single lengths, without joints, which will not exceed $21\frac{1}{4}$ feet.

The simplest way of calculating the strains is to consider them first as for a Warren girder, and then the sectional area of iron required can be split up into as many lattice bars as may be convenient.

The quantities of iron are theoretically as the linear dimensions multiplied by the pressures, and divided by the safe strains per square inch.

These come out very simply, and the formulæ from which they are derived are easily recognisable.

The theoretical quantities have then to be modified for connections and stiffenings, and, following Mr. Bindon Stoney's method, the process is given below:—

The tension bracing, is half the whole bracing, and the weight is—

Sec. θ Cosec θ. Distributed Load.

$$\frac{2\cdot31}{2} \times \frac{522}{4} \times \frac{200' \text{ sp.}}{5' \text{ sq.}} \times \frac{1}{144} = 41\cdot8 \text{ cubic feet iron.}$$

41·8 cubic feet iron, at 4·6 cubic feet per ton = ...	9·08	tons.
Compression bracing = $\frac{5}{4}$ of tension = ...	11·18	"

Tension flanges $= \frac{wl^2}{12fd} = \frac{522}{12} \times \frac{200 \times 200}{5 \times 16\cdot7} \times \frac{1}{144}$ c. ft.

or	31·60	"
Compression $\frac{5}{4}$ of the tension flange, ...	39·50	"
Total theoretic weight, ...	91·36	"

For the true quantities we have the following :—

Theoretic tension bracing, ...	9·08 tons.	
Add rivet holes, say, ¼ the net section,.. ...	2·26	11·34
Theoretic compression bracing, ...	11·18	
Add stiffening, 100 per cent., ...	11·18	
Theoretic tension flange, ...	31·60	
Rivet holes, ¼ net section, ...	6·32	
Covers, ⅛ of whole flange, ...	4·74	42 66
Theoretic compression flange, ...	39·50	
Covers of compression ⅛ flange, ...	4·94	44·44
True total, ...		
Add rivet heads, flange, bolts &c., $\frac{1}{10}$, ...		
4 end pillars, at and, crossing bracing,		
Add cross girders,		
Contingencies,		
Total,		212·00 tons.

The true quantities of iron in all the parts have now to be divided between the members in proportion to the length and the strains.

The strains in the top and bottom flanges diminish in regular parabolic ratio from the middle of the span towards the ends. Those in the bracing lattice bars increase in arithmetical progression from the middle towards the ends. The division of the total weight for each of the three principal members, top and bottom flanges and connecting web, in the above proportion is a mere matter of arithmetic. The results are given on the face of *Plate* VII.

The weights of each section of the girder and the lengths being now ascertained, the sectional areas are easily derivable. In this particular case, the sectional areas are then divided into four double lattice bars for the web, which gives a support at 4·8 feet central distance in every part of the girder.

Total cost of the Nerbudda Bridge.

If the foregoing be accepted as an average plan, it will give a bridge costing £10,000 of 200 feet span, or £50 per foot of single line.

For the Nerbudda Bridge 3,600 feet long, the cost would consequently be £180,000.

The existing bridge appears to have cost £47·77 at the least computation. It has, no doubt, cost much more owing to failures and reconstruction. It is certainly for a double line, but the second line has never been used, and were the traffic sufficient to demand its use, it is doubtful if the structure would stand the work long. When we come to consider what a large traffic might we worked over a single line bridge, even on a double line of railway, it must be unwillingly conceded that a second line will be ever required on the Bombay, Baroda, and Central India Railway, over the few exceptionally long bridges, and the saving in the original cost of a single over that of a double line must always be a great consideration in the capital account.

At the same time, double line bridges, though they might cost double as much as single ones, would allow of much more than double the useful work being done over them, and may be required for the short bridges when they are numerous.

We have seen that for a 200 feet span, single line, about 212 tons of iron are required. For a double line, a 120 feet span could be made for about the same weight, as will be seen on referring to the table:—

Weight of main girders, &c., ...	120·2 tons.
Cross girders, at 0·72 tons per foot, ...	86·4 „
Total, ..	206·6 „

The cost would be about £41·7 a foot for the *span* alone for a double, against the £25·0 a foot for the *span* alone of a single line.

But as regards the cost of a double line *bridge*, if the piers as designed were lengthened only, and would then be considered thick and strong enough for a double line of 20 per cent. less span, the ironwork in them would be increased about 53 per cent., and all other items 69 per cent., making the cost of a *pier* £7,905. This would give, at £24 a ton, 329·4 tons for the weight of iron in the *span*.

From the table, it appears that under these circumstances, a span of 160 feet would be most suitable, giving the weight of—

Main girders, &c., about	225 tons.
Cross girders, ...	115 „
Total, ..	340 „

The cost per foot of *bridge*, including piers, would in this case be about—

$$\frac{7,905 \times 2}{160} = £99 \text{ a foot,}$$

or a little less than double the cost for a single line.

Were the same span adhered to for both single and double line, and the pier as designed, lengthened and thickened to preserve the same relative advantages as regards the loads on the spans and foundations, the cost would be increased, the ironwork about 83·6 per cent., and the other items about the same, making the cost of a pier £9,308.

The cost of the spans would be—

Girders,	170·64 × 2	=	341·28 tons.
Cross do.,	0·72 × 200	=	144·00 tons.
	Total, ...		485·28, at £24 a ton = £11,646.

The cost of the bridge would then be—

$$\text{Piers, ...} \quad \frac{9,308}{200} = £46·54$$

$$\text{Span, ...} \quad \frac{11,646}{200} = 58·23$$

Total, ... £104·77 or about 5¼ per cent. more.

Showing that it would be cheaper to reduce the span for a double line.

T. F. D.

No. CCXVII.

DISCUSSION OF THE MOST RECENT EXPERIMENTS ON VELOCITY-DISTRIBUTION IN A CHANNEL.

[*Vide* Plates VIII., IX. and X.]

BY MR. L. BAZIN, *Ingénieur des Ponts et Chaussées.*

Transl. by CAPT. ALLAN CUNNINGHAM, R.E., *Hon. Fell. of King's Coll., Lond.*

Translator's Preface.

THIS Essay is translated (with the author's permission), from the "Annales des Ponts et Chaussées," Vol. X. of 1875. It is an exhaustive discussion of the Experiments then available (1875) on the figure of the Vertical Velocity-Curve in a wide channel: it does not of course include the Results of the following experiments :—

1°. Paraná, Uruguay, and La Plata, by Mr. J. G. Révy, pub. in 1874.

2°. Connecticut, by Gen. Theo. G. Ellis, pub. in 1875.

3°. Roorkee, by the present writer, pub. in 1875.

The author's strongly expressed opinion adverse to the use of the "Double Float" cannot fail to excite serious consideration, and acquires additional importance at the present time in consequence of the recent publication of the extensive Experiments on the Irrawaddi, and of the no less extensive Experiments still in progress at Roorkee, in both of which the "Double-Float" was largely used.

The translator must not be held to endorse the author's condemnation of the "Double-Float" when used with suitable precautions, at any rate for channels of moderate depth; the "vertical velocity-curves" resulting from the Roorkee Experiments do not present the anomalies pointed out by the author in the Mississippi and Saïktha Curves, and will be found to follow pretty closely in different parts of the same section the variation of form indicated in the Plates of the author's "Recherches Hydrauliques," the line of maximum velocity invariably sinking with approach to the banks.

The attacks made in several quarters on the Mississippi Experiments about the thickness of cord (stated to be ·2") used for the Double Floats, has elicited* a spirited defence of the Double Float by the authors of the Mississippi Report, and the important statement that the thickness was only ·1", and that the figure ·2" before given was an error.

* "Annual Report of the Chief of Engineers for 1875"—Appendix AA 15, page 114, by Genl. A. A. Humphreys, Washington, 1875.

On Velocity-Distribution in a Channel.

The distribution of velocity in a current has already been the aim of numerous experiments which are far from being accordant even in the simplest case of a channel of great width, in which the effect of the banks may be disregarded: these experiments present in the case of a large body of water considerable practical difficulties, and the highly variable and capricious nature of the phenomena, the real laws of which are liable to be masked by a host of secondary influences, greatly increase these difficulties. However hydraulicians admit generally now-a-days that the velocities across the same vertical vary as the ordinates of a parabola; the greatest velocity is sometimes at the surface, sometimes below, and hitherto it has not been possible to estimate the causes which govern its change of position. According to this parabolic law, the velocity v at a given point of any vertical depends on its depth h below the surface according to the very simple formula

$$v = \mathrm{V} - \mathrm{M}\left(\frac{h - h'}{\mathrm{H}}\right)^2$$

in which h' denotes the distance from the vertex of the parabola to the surface, H the full depth, and V the maximum velocity. Replacing, for greater simplicity, the ratios $h \div \mathrm{H}$, and $h' \div \mathrm{H}$ by x and a, we may write,

$$v = \mathrm{V} - \mathrm{M}(x - a)^2, \ldots\ldots\ldots\ldots\ldots\ldots (1).$$

Several remarkable relations are easily deduced from this equation.

We have firstly, for the mean (u) of all velocities on the same vertical,

$$u = \int_0^1 \left\{\mathrm{V} - \mathrm{M}(x - a)^2\right\} . dx = \mathrm{V} - \mathrm{M}\left(\tfrac{1}{3} - a + a^2\right), \ldots(2).$$

Denoting, according to the notation used by Messrs. Humphreys and Abbot in their great work on the Mississippi, by v_x the velocity at depth x, so that v_0, $v_{\frac{1}{2}}$, $v_{\frac{3}{5}}$, ...denote the velocities at the surface, at one-half, three-fifths,......of the depth, it is easy to see that the mean of the velocities v_x, v_{1-x}, equidistant from the surface and bottom differs but little from u; in fact,

$$\frac{v_x + v_{1-x}}{2} = \mathrm{V} - \mathrm{M}\left(x^2 - x + a^2 - a + \tfrac{1}{2}\right) = u - \mathrm{M}\left(x^2 - x + \tfrac{1}{6}\right),$$

an equation not involving a. The factor multiplying M vanishes when $x = \frac{1}{2}\left(1 \pm \sqrt{\frac{1}{3}}\right)$, or approximately when $x = \frac{1}{5}$ or $\frac{4}{5}$.

By making $x = \frac{1}{2}$ in the above formula, there results

$$v_{\frac{1}{2}} = u + \tfrac{1}{12} M.$$

Thus the mid-depth velocity differs from the mean velocity only by the small quantity $\frac{1}{12}$ M, whatever be the position of the axis of the parabola. Messrs. Humphreys and Abbot have based on this property a rapid mode of river-gauging. Further the velocity at $\frac{2}{3}$ of the depth, although not independent of a, differs still less from u, for

$$v_{\frac{2}{3}} = u - \tfrac{1}{3} M \left(\tfrac{2}{15} - a\right)$$

an expression which varies only from $(u - \frac{2}{75} M)$ to $(u + \frac{1}{25} M)$, whilst a itself varies from 0 to $\frac{1}{5}$, which limits comprise most of the cases of practice.

These relations are very simple consequences of the parabolic law, and obtain for all values of M. But can we admit, that *cæteris paribus* this parameter is itself independent of the position of the axis of the parabola? Were it so, when the vertex of the parabola is below the surface, the difference $(V - v_1)$ between the maximum and bottom velocities (V, v_1) being diminished in the ratio $1 : (1 - a)^2$, the ratios $V \div u$ and $v_1 \div u$ should approximate very closely to unity. Experiment on the other hand assigns to them nearly constant values; M should therefore increase with a so as to preserve the difference $\left(\frac{V}{u} - \frac{v_1}{u}\right)$ nearly constant. This condition is satisfied by changing M in Eq. (1) into $M \div (1 - a)^2$; whence,

$$v = V - M \left(\frac{x - a}{1 - a}\right)^2 \qquad (3).$$

Let us submit this hypothesis to the test of experiment, and at the same time endeavor to find the general expression for M. The data available for this investigation form four very distinct categories:

1°. Experiments on the small scale reported in Chap. III. and IV. (Part iii.) of the author's "Recherches Hydrauliques".
2°. Experiments in Europe on great bodies of water (the Seine, Saône, &c.)
3°. Experiments of Messrs. Humphreys and Abbot on the Mississippi.
4°. Experiments of Mr. Robt. Gordon on the Irrawaddi.

1°. Experiments on the small scale.

These experiments were executed by means of M. Darcys "gauge-tube" on very regular channels of about 2 mètres ($6\frac{1}{2}'$) width; the observed velocities were pretty high, and the maximum velocity was commonly at the surface. In the discussion of the experiments in which this latter condition is best satisfied, we were led* to assign to the parameter M the value $M = 20\sqrt{HI}$ (I being the slope of the channel), so that the equation of the parabola becomes

$$v = V - 20\sqrt{HI}\,x^2, \qquad (4).$$

See Plate XXIV., *Fig.* 1, of the *Recherches Hydrauliques* for the graphic representation of the results of this discussion; by calculating the values of $(V - v) \div \sqrt{HI}$ for each of the velocities across the same vertical line passing through the axis of the stream, and plotting each of these values as the ordinate (y) of a point whose abscissa is the corresponding value of x, it is seen at once that all the points so found lie close to a single parabola $y = 20\,x^2$; this proves the law stated.

In this discussion, seven experiments, in which the maximum velocity was below the surface were disregarded: according to the hypothesis just made for the general expression for M, Eq. (4) should in this case be replaced by the following:—

$$v = V - 20\sqrt{HI}\left(\frac{x - a}{1 - a}\right)^2, \qquad (5).$$

To extend the same mode of graphic representation to this equation, let us take as ordinates y' the values of $\frac{V - v}{\sqrt{HI}}\,(1 - a)^2$, and as abscissæ those of $(x - a)$; we must then see if the points so found lie close to the parabola $y' = 20\,x'^2$.

The Table below shows the data of the seven experiments which we are about to discuss, and also along with them those of the eight experiments represented on Plate XXIV. of the "Recherches Hydrauliques"†

The first columns of this Table call for no remark; the two last show the value of the maximum velocity V, and that of the ratio a ($= h' \div H$) which fixes its depth below the surface. It is clear that in consequence of experimental errors, there is always some uncertainty as to the position of the maximum velocity, so that a cannot be determined within about ·05 ($= \frac{1}{20}$). As to V, the velocities measured near the vertex of the parabola give a sufficiently close value. Thus may be found quite accurately enough the quantities $y' = \frac{V - v}{\sqrt{HI}}\,(1 - a)^2$ and $x' = x - a$

* See *Recherches Hydrauliques*, page 228, *et seq.*

† *See* also Plates XIX., XX. of the same for the data of these 15 experiments.

Detail of Experiments.	Slope. L	Depth. H.	Value of parameter. $\sqrt{HI}$	Maximum velocity. V.	Value of a defining the position of max. veloc$y$.
1°. Smooth sides, &c., of plaster or of planks.					
		mètres		mètres	
Series No. 55.—Experiment No. 1.—Channel in plaster of width $1^m.81$, ..	·0049	·269	·0363	3·02	zero.
„ 58.— „ 3.—Channel of plank „ $1^m.99$, ..	·0015	·332	·0223	1·50	zero.
„ 58.— „ 4.— „ „ „ „ ..	·0015	·436	·0256	1·74	·15
„ 59.— „ 4.— „ „ „ „ ..	·0059	·265	·0395	2·87	zero.
2°. Slightly rough sides, &c., (small gravel, planks covered with strips ·01 metre apart.)					
Series No. 56.—Experiment No. 1.—Channel lined with coarse gravel, (of width $1^m.83$), ...	·0049	·394	·0439	2·35	·20
„ 61.— „ 3.—Channel of plank covered with strips ·01 mètre apart (of width $1^m.97$), ...	·0015	·377	·0238	1·45	zero.
„ 61.— „ 4.— „ „ „ „	·0015	·495	·0272	1·65	·30
„ 62.— „ 4.— „ „ „ „	·0059	·320	·0435	2·54	zero.
„ 63.— „ 3.— „ „ „ „	·0089	·286	·0505	2·84	zero.
3°. Sides lined with coarse gravel, or plank covered with strips ·05 metre apart.					
Series No. 57.—Experiment No. 1.—Channel lined with coarse gravel (of width $1^m.86$), ...	·0049	·452	·0471	2·08	·25
„ 64.— „ 1.—Channel of plank covered with strips at ·05 mètre apart (of width $1^m.97$), ...	·0015	·487	·0270	1·19	·25
„ 64.— „ 2.— „ „ „ „	·0015	·660	·0315	1·26	·35
„ 65.— „ 3.— „ „ „ „	·0059	·322	·0436	1·84	zero.
„ 65.— „ 4.— „ „ „ „	·0059	·442	·0493	2·09	·15
„ 66.— „ 2.— „ „ „ „	·0089	·380	·0582	2·34	zero.

which form the basis of the graphic representation on *Plate* X. An inspection of *Fig.* 1 will show that almost all the points lie close to the parabola $y' = 20\ x'^2$. In estimating the degree of discrepancy, it must be observed that a somewhat slight error in one of the velocities makes a considerable change in the ordinates y' which depend only on their differences. The parabola represents then the results of experiment as well as can be expected.

If we wished on the other hand to suppose M constant, and thus to apply Eq. (4) instead of Eq. (5) to these experiments in which a differs from zero, y' must be replaced by $y = \frac{V - v}{\sqrt{HI}}$, and the ordinates being thus increased in the ratio $1 : 1 \div (1 - a)^2$, the points so determined will lie further from the parabola the more a increases. These values of y are shown (*Fig.* 2) for the seven experiments in question, and it is seen that all the points are actually above the parabola: the impossibility of retaining Eq. (4) in this case is rendered obvious, and Eq. (5) alone remains applicable.

This latter may be written in a slightly different form, which is often more convenient, dividing both sides of the equation by u, it becomes

$$\frac{v}{u} = \frac{V}{u} - 20 \sqrt{\frac{HI}{u^2}} \left(\frac{x - a}{1 - a}\right)^2$$

In a body of water of great width, in which the effect of the banks is negligible, H would merge into the hydraulic mean depth R, u into the "mean velocity" (U) of the whole cross section, and as the ratio $HI \div u^2$ would thus pass into the known coefficient $RI \div U^2$ (to be denoted by A), the equation of the parabola might be written,

$$\frac{v}{u} = \frac{V}{u} - 20 \sqrt{A} \left(\frac{x - a}{1 - a}\right)^2 \quad \text{.........................(6).}$$

In this form it contains only ratios; it is therefore better fitted to give an accurate idea of the distribution of velocity, the ratios only—and not the actual values of the velocities in each particular case,—being the object of research.

As the channels in question were only about 1·8 or 2 mètres in width, the quantities $\sqrt{\frac{HI}{u^2}}$ and $\sqrt{A}$ differ by hardly more than a few hundredths more or less*; let us suppose them equal, and replace Eq. (5) by Eq. (6)

* The difference by direct calculation for the 15 experiments is generally much less than $\frac{1}{20}$ of $\sqrt{A}$; only two experiments give a difference exceeding this.

the parameter is then proportional to the coefficient $\sqrt{A}$, which thus becomes the "modulus" of the velocity-variation. Again, the formula (2) which connects the mean and maximum velocities may be written

$$\frac{V}{u} = 1 + \frac{M}{u}\left(\tfrac{1}{3} - \alpha + \alpha^2\right)$$

or, substituting for M its new value

$$\frac{V}{u} = 1 + 20\sqrt{A} \cdot \frac{\frac{1}{3} - \alpha + \alpha^2}{(1 - \alpha)^2}, \qquad (7).$$

This formula assigns to the ratio $V \div u$ values increasing with A; as the factor which multiplies $\sqrt{A}$ lies always between $\frac{1}{3}$ and $\frac{1}{4}$, they vary but little with α, as is readily shown by calculating their values for the most usual values of $\sqrt{A}$.

Value of $\sqrt{A}$.	Values of $V \div u$ for				
	$\alpha = 0$	$\alpha = \frac{1}{10}$	$\alpha = \frac{1}{5}$	$\alpha = \frac{1}{3}$ (minimum)	$\alpha = \frac{1}{2}$
·015	1·100	1·090	1·081	1·075	1·100
·020	1·133	1·120	1·108	1·100	1·133
·025	1·167	1·150	1·135	1·125	1·167

Let us now apply the formulæ (6), (7) to these 15 experiments; the coefficient $\sqrt{A}$ being known for each of them, the ratios $V \div u$ and the parameters $20\sqrt{A} \div (1 - \alpha)^2$ corresponding are deduced as follows.

An inspection of the Table (on next page) shows that the ratio $V \div u$ varies between extreme limits 1·09 and 1·19 according to the nature of the sides. *Cæteris paribus*, this ratio decreases somewhat when the maximum velocity is below the surface. When $\sqrt{A} = {\cdot}02$, then $V \div u = 1{\cdot}10$ to 1·13; this value will recur below in the case of large bodies of water.

2°. Experiments in Europe on large bodies of water.

The measurement of velocity in a large body of water presents serious difficulties. The meter used for the experiments about to be dis-

Detail of Experiments.	Value of $\sqrt{A}$.	Elements of Parabola $\frac{v}{u} = \frac{V}{u} - \frac{20\sqrt{A}}{(1-a)^2}(x-a)^2$: $\frac{V}{u}$	$\frac{20\sqrt{A}}{(1-a)^2}$	a
1°. Smooth sides, &c., of plaster or plank.				
Series No. 55.—Experiment No. 1.—Channel of plaster, ...	·0131	1·087	·262	zero.
„ 58.— „ 3.—Channel of plank, ...	·0157	1·105	·314	zero.
„ 58.— „ 4.— „ „	·0150	1·085	·415	·15
„ 59.— „ 4.— „ „	·0149	1·099	·298	zero.
2°. Slightly rough sides, &c., (small gravel, plank covered with strips, ·01 metre apart.)				
Series No. 56.—Experiment No. 1.—Channel lined with small gravel, ...	·0217	1·117	·678	·20
„ 61.— „ 3.—Channel of plank covered with strips at ·01 mètre apart,	·0188	1·125	·376	zero.
„ 61.— „ 4.— „ „ „	·0184	1·092	·751	·30
„ 62.— „ 4.— „ „ „	·0191	1·127	·382	zero.
„ 63.— „ 3.— „ „ „	·0200	1·133	·400	zero.
3°. Sides, &c., lined with coarse gravel, or plank covered with strips at ·05 metre apart.				
Series No. 57.—Experiment No. 1.—Channel lined with coarse gravel, ...	·0257	1·133	·914	·25
„ 64.— „ 1.—Channel of plank covered with strips at ·05 mètre apart,	·0258	1·134	·917	·25
„ 64.— „ 2.— „ „ „	·0257	1·129	1·217	·35
„ 65.— „ 3.— „ „ „	·0287	1·191	·574	zero.
„ 65.— „ 4.— „ „ „	·0278	1·159	·770	·15
„ 66.— „ 2.— „ „ „	·0288	1·193	·576	zero.

cussed acts very well near the surface; but when it is wished to penetrate into the deeper layers of the stream, the vibration and bending of the rod which carries the instrument, often interfere with its working. This inconvenience is most sensible close to the bottom: if the meter is too near the bottom, it works in an irregular manner, and the resulting velocities are obviously too low. This source of error explains certain anomalies which will appear further on.

The experiments, the results of which it is now proposed to discuss, are 12 in number, viz.,

1°. Seven experiments on the Saône, made in 1859 at Raconnay, 19 kilomètres above Châlon, under superintendance of M. Léveillé.* They were all made at one cross-section: the velocities were measured upon verticals regularly spaced at 20 mètres apart, and at five points on each vertical, the two extreme points being as close as possible to the surface and bed, and the remaining three equidistant, dividing the depth into quarters.

2°. One experiment on the Seine made at Meulan in 1852, under superintendance of M. Emmery†; the velocity-measurements, instead of regularly subdividing all the depths proportionally, were distributed at successive depths of ½ mètre.

3°. Two experiments by Mr. Baumgarten on the Garonne; they were made, one in 1845 at two kilomètres above Marmande, the other in 1841 at 21 kilomètres below; the velocity-measurements were irregularly spaced, which makes their discussion more difficult.

4°. One experiment by M. Defontaine on an arm of the Rhine at Kehl‡.

5°. One experiment made in 1867 on the Rhine at Basle, by a commission of engineers of the neighboring States §; the velocities were measured on only a small number of verticals.

On *Plates* VIII., IX. are shown the cross-sections of each channel, with the velocities determined at various points of the cross-section; the Table below shows the principal elements of these experiments.

* For these Experiments, *see* the Table of page 309 of "Recherches Hydrauliques," (Exp. Nos. 4 to 10 of Series 3°).

† *See* the same Table, (Exp. No. 2 of Series 2°).

‡ Annales des Ponts et Chaussées, 1833, Second half-year.

§ Die Internationale Rheinström Messung bei Basel, vorgenommen an 6-12 Nov. 1867, von H. Grebenau, Munich, 1873.

Detail of Experiments.		Fall per kilomètre. 1000 I.	Mean Depth at mid-stream. H.	Value of Parameter. $\sqrt{HI}$	Maximum Velocity. V.	Value of a defining the depth of the maximum velocity.
Saone at Raconnay,	Experiment No. 1,	·040	3·30	·0115	·595	·10
	" 2,	·040	3·99	·0126	·700	·15
	" 3,	·040	4·25	·0130	·715	·15
	" 4,	·040	4·34	·0132	·725	·15
	" 5,	·040	4·84	·0139	·830	·20
	" 6,	·040	5·30	·0146	·905	·20
	" 7,	·040	5·73	·0151	·905	·20
Seine, at Meulan,	Verticals 10 to 13,	·087	2·85	·0157	·848	zero.
	" 14 to 18,	·087	2·51	·0148	·865	·10
	" 19 to 22,	·087	3·30	·0169	·958	zero.
Garonne, near Marmande,	Experiment of 1845,	·210	2·82	·0244	1·417	zero.
	" 1841,	·340	4·07	·0372	2·040	·20
Branch of Rhine at Kehl, ...		·398	1·50	·0244	1·230	zero.
Rhine, at Basle,	Vertical No. 2, ..	1·218	2·85	·0589	2·636	zero.
	Verticals Nos. 3&4,	1·218	2·62	·0565	2·450	zero.

The values of H and V recorded in this Table are the means calculated for a certain number of verticals about mid-stream, where the effect of the banks may be considered negligible, viz. :—

Saône, at Raconnay.—Verticals Nos. 2 to 7.

Seine, at Meulan.—Verticals Nos. 10 to 22: in consequence of the considerable differences in depth, and of the changes occurring in the surface-level during the course of the experiment, it has been thought necessary to take out three separate means, viz., Nos. 10 to 13, 14 to 18, and 19 to 22.

Garonne.—Experiment of 1845. Verticals Nos. 3 to 8.

Garonne.—Experiment of 1841. Verticals Nos. 3 to 5. (The verticals Nos. 6 to 8 do not give a number of points sufficient to determine the law of velocity-variation).

Branch of the Rhine, at Kehl.—Verticals Nos. 2 and 3.

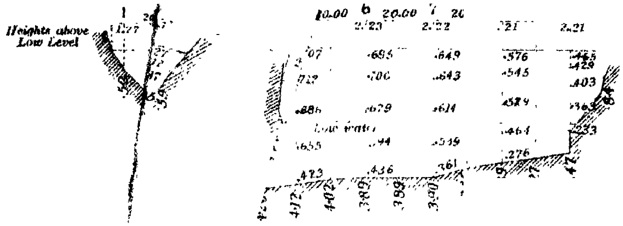
Rhine, at Basle.—Verticals Nos 2 to 4; the water-level having changed, the vertical No. 2 has been taken separately.

The last column of the Table gives the value of a, which involves—as already remarked—a certain indeterminateness.

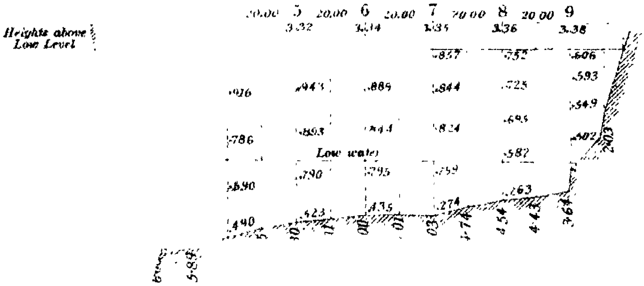
By help of these data, we can calculate the values of $x' = x - a$, and $y' = \frac{V - v}{\sqrt{HI}}(1 - u)^2$, so as to see if they satisfy the equation $y' = 20\, x'^2$.

CHANNEL.

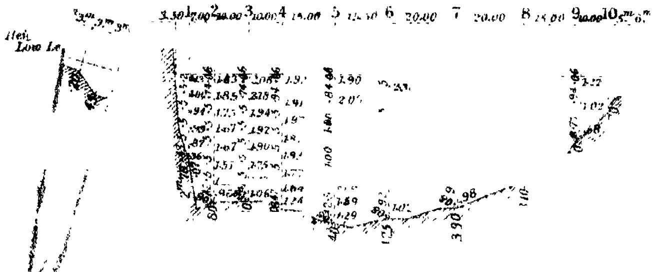
.xperiment No 3



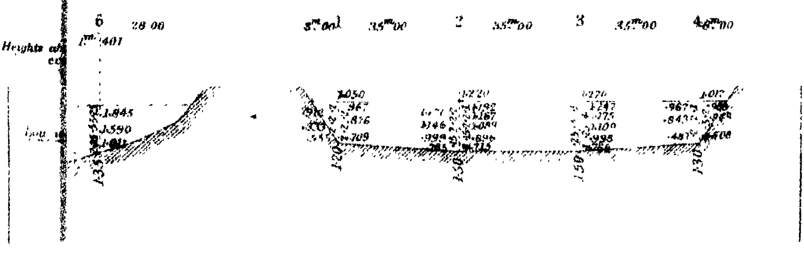
g 8, Saône—Experiment No 6



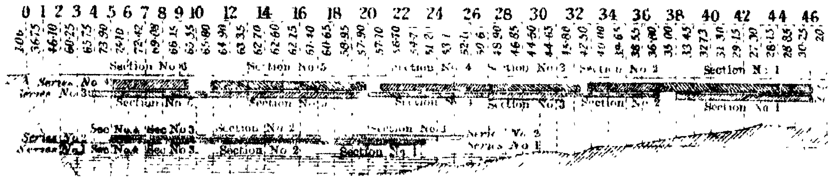
A Fig 9, Garonne—Experiment of 184



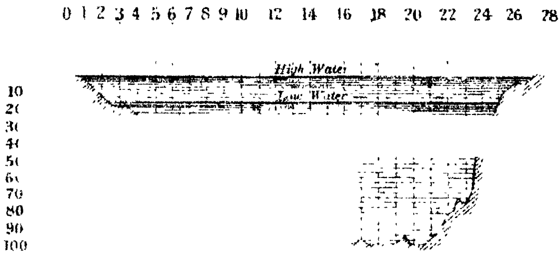
A Fig 12, Branch of Rhine at Kehl



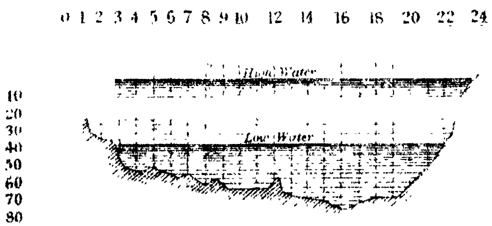
C Fig 13, *Irrawaddi at Saiktha*



C Fig 14, *Mississippi at Carrollton*



C Fig 15 *Mississippi at Columbus*



SCALES C—Irrawaddi and Mississippi

Breadths, 1 mètre to 40,000 feet

The calculation of the velocities (v) presents no difficulty in the case of the Saône; the velocity-measurements having been spaced so as to sub-divide the whole depth (H) into quarters, we can—without taking into account the differences of depth on each of the six verticals—take the mean of the several velocity-measurements at the surface, quarter-depth, half-depth, &c. This proportional sub-division was not followed in the case of the Seine; but, as the points chosen for velocity-measurement sub-divide the verticals into five or six nearly equal parts, an easy interpolation gives the velocities at depths $\frac{1}{5}$ H, $\frac{2}{5}$ H, &c.,......or at $\frac{1}{6}$ H, $\frac{2}{6}$ H, &c., and we can then take out—as in the case of the Saône—the means for the homologous points. The same process of interpolation has been applied to the two experiments on the Garonne; as to those on the Rhine, where there were but few verticals, the mode of sub-division adopted by the experimenters has been nearly followed.

By plotting—as in the experiments on the small scale—the points defined by the co-ordinates x', y', (*see Fig.* 3, *Plate* X.,) it is seen as before that they lie close to the parabola. The only noticeable feature is that the points corresponding to velocities measured at a short distance from the bottom are all sensibly above the curve, which shows a more rapid decrease of velocity in that region; nevertheless, it may well happen that this peculiarity is simply the result of experimental error, the meter not recording accurately when placed only a few centimètres above the more or less irregular river bed: this source of error has clearly affected some experiments which it has therefore been considered necessary to reject, and it is probable that none of them are quite free from this.

If—in those experiments in which a differs from zero—we replace the ordinates y' by $y = (V - v) \div \sqrt{HI}$, we prove again (*see Fig.* 4, *Plate* X.) that the suppression of the factor $(1 - a)^2$ raises all the points much above the parabola, so that the parameter cannot be independent of a.

The values of A differing but little in the case of the rivers, it might be expected that the ratio $V \div u$ would remain nearly constant; formulæ (6, 7), assign in fact to this ratio and to the parameter of the parabola the following values.*

* The values of $\sqrt{HI} \div u^2$ and $\sqrt{A}$ differ still less than in the experiments on the small scale; the discrepancy is everywhere less than $\frac{1}{20}$.

Detail of Experiments.			Value of $\sqrt{A}$.	Elements of Parabola $\frac{v}{u} = \frac{V}{u} - \frac{20\sqrt{A}}{(1-a)^2} \cdot (x-a)^2$.		
				$\frac{V}{u}$	$\frac{20\sqrt{A}}{(1-a)^2}$	a
Saone at Raconnay,	Experiment No. 1,	..	·0214	1·128	·528	·10
	" 2,	..	·0204	1·116	·565	·15
	" 3,	..	·0204	1·116	·565	·15
	" 4,	..	·0203	1·116	·562	·15
	" 5,	..	·0185	1·100	·578	·20
	" 6,	..	·0185	1·100	·578	·20
	" 7,	..	·0192	1·104	·600	·20
Seine, at Meulan,	Verticals 10 to 13,	..	·0203	1·135	·406	zero.
	" 14 to 18,	..	·0203	1·122	·501	·10
	" 19 to 22,	..	·0203	1·155	·406	zero.
Garonne, near Marmande,	Experiment of 1845,	..	·0200	1·153	·400	zero.
	" of 1841,	..	·0190	1·103	·594	·20
Branch of Rhine, at Kehl,		..	·0227	1·151	·454	zero.
Rhine at Basle,	Vertical No. 2,	..	·0260	1·173	·520	zero.
	Verticals Nos. 3, 4,	..	·0260	1·173	·520	zero.

It is seen that the ratio $V \div u$ lies commonly between 1·10 and 1·13; it rises in the case of the experiments on the Rhine at Basle to the unusually high value 1·17, in consequence of the peculiar nature of the bed which consists of large boulders. The parameter lies between ·4 and ·6.

3°. Experiments of Messrs. Humphreys and Abbot on the Mississippi.

Messrs. Humphreys and Abbot carried out large series of Discharge-measurements on the Mississippi in 1851 and 1858, from which alike they deduced the parabolic law, assigning however to the parameter values very different from those resulting from the European experiments*. The enormous depth of the river not admitting the easy use of the meter, they had recourse to the method of double floats; the lower float consisted of a cask loaded with lead; a cord of length equal to the depth proposed to be attained, connected it with a surface-float carrying a small flag; the passage of this flag past two parallel lines of sight 200 feet apart, was observed with telescopes from the bank. At great depths this apparatus clearly does not show the velocity of the stream at the point to which its lower end reaches; for the cord and the surface float being plunged in layers of greater velocity, tend to move quicker than the lower float, and the latter is thus dragged on in a decidedly

* Report upon the Physics and Hydraulics of the Mississippi River, by Capt. A. Humphreys and Lieut. L. Abbot, Philadelphia, 1861.

PLATE X.

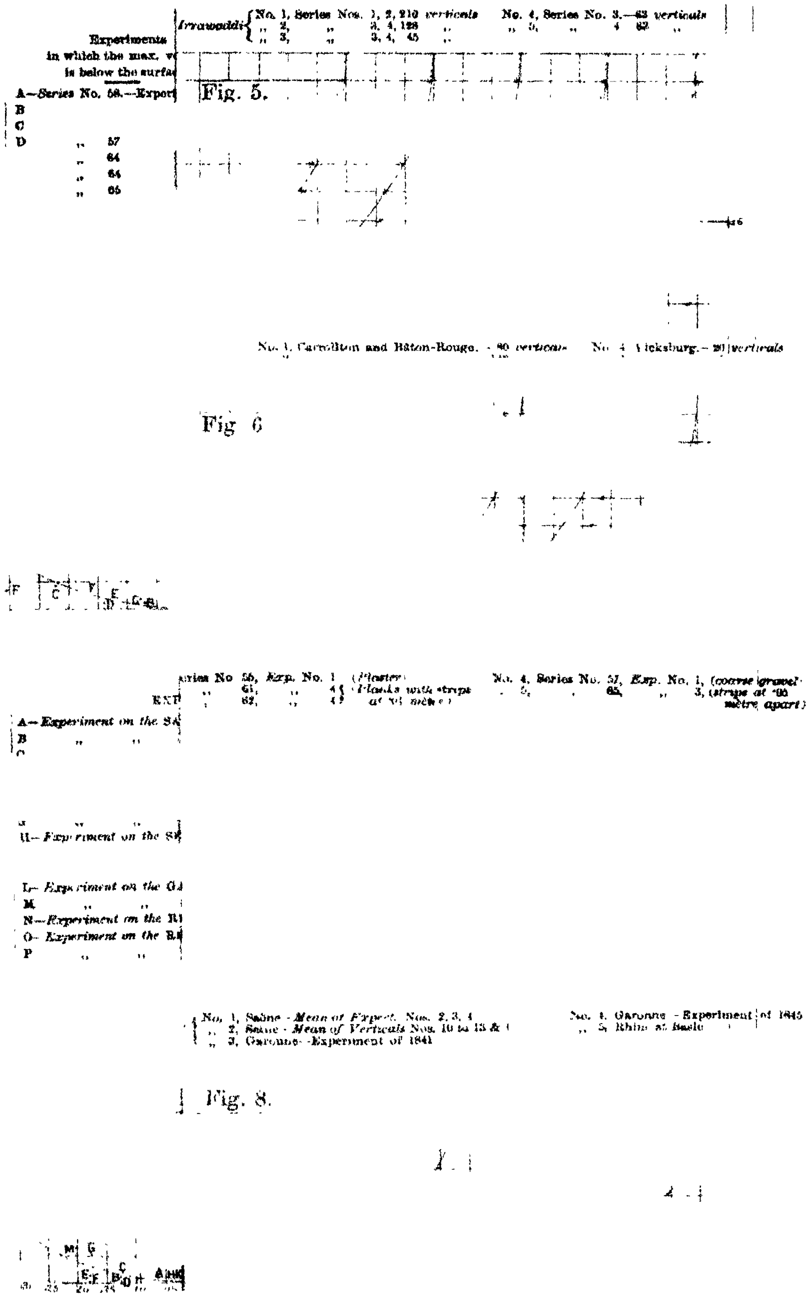


Fig. 5.

Fig 6

Fig. 8.

marked manner; the error thus committed increases continuously with the depth, and too small a value results for the parameter of the parabola.

The experiments in 1851 were of great importance in Messrs. Humphreys and Abbot's work: they are recorded* with all their elements in six Tables, which show the velocities measured on a certain number of verticals, the depth of water corresponding, the direction of the wind, &c.; the observations having been made at six different sections,† and in different states of the river have no immediate mutual connexion. To disengage from these somewhat discordant results, the expression of a law, Messrs. Humphreys and Abbot took out the mean of velocities obtained at corresponding points on the verticals of each Table; these means are collected below.

It suffices to glance at these Tables to see that the velocities on the same vertical vary much less in them than in the European experiments. This might be foreseen, since the method of double floats tends to give too high velocities for the deeper layers of the stream. Messrs. Humphreys and Abbot appear it is true to anticipate this objection.‡ "The size (of the lower float) was so much greater than that of the surface float, that the latter did not sensibly affect the rate of movement. This assumption was tested by placing the apparatus in still water during a high wind, and also by noticing the direction of the paths of the floats during a gale blowing directly across the river. No wind effect of consequence could be detected in either case." This remark merely proves that the effect of the surface-float is insensible which will be readily admitted; but as to the cord which connected it to the sunken float, it naturally leaves it out of consideration, because it was not subjected to the action of the wind. But it is quite a different matter in a stream. Suppose in fact, to fix the ideas, a depth of 30 mètres (about 98′), and the lower float placed as near the bottom as possible so to give the velocity v_1.

Its section $\cdot 38 \times \cdot 25 = 9{\cdot}5$ sq. décimètres—though far greater than that of the surface-float, the neglect of which is fairly admissible,—is less than that of the cord which exposes to the current an area of $\cdot 005 \times 30 = 15$ sq. décimètres; the mean velocity of the layers which this cord pierces being sensibly equal to u, the complete apparatus will not show the bottom velocity v_1, but a velocity intermediate to v_1 and u, and nearer u than v_1.

* *See Report upon the Mississippi*, pages 280—282.
† *See Plate* IX., for the principal section at Carrollton.
‡ *Report upon the Mississippi*, page 224.

DETAIL OF SERIES OF EXPERIMENTS.	DEPTHS.
	1°. Experiments made at
Table I	
72 experiments on 13 verticals at 3 different sections,	105′ to 110′ (32^{m} to 33^{m}·5),
Table II	
42 experiments on 8 verticals at 3 different sections,	65′ to 70′ (19^{m}·8 to 21^{m}·3),
Table III	
28 experiments on 4 verticals at 3 different sections,	50′ to 55′ (15^{m}·3 to 16^{m}·8),
	2°. Experiments made at low water
Table IV	
24 experiments on 5 verticals at one section at Carrollton, ...	95′ to 100′ (29^{m} to 30^{m}·5),
Table V	
20 experiments on 3 verticals at 2 different sections, (one at Carrollton, one at Bâton Rouge,) ..	75′ to 80′ (22^{m}·9 to 24^{m}·4),
Table VI	
36 experiments on 6 verticals at 3 different sections, (one at Carrollton, two at Bâton-Rouge.) ..	55′ to 65′ (16^{m}·8 to 19^{m}·8),

Besides the above principal experiments which were made with great
1858 on the Mississippi at Vicksburg and at Columbus,* and in 1851

DETAIL OF SERIES OF EXPERIMENTS.	DEPTHS.
	1°. Experiments on the Missis-
Table VII	
Columbus.—52 experiments on 18 verticals..	55′ to 75′ (16^{m}·8 to 22^{m}·9),
Table IX	
Vicksburg.—20 experiments on 10 verticals,	45′ to 65′ (13^{m}·7 to 19^{m}·8),
Table VIII	
Vicksburg.—3 experiments on 2 verticals, .	75′ (22^{m}·9),
	2°. Experiments at Bayous
Table X	
Bayou Plaquemine.—8 experiments on 1 vertical,	27′ (8^{m}·2),
Bayou La Fourche.—6 experiments on 1 vertical,	27′ (8^{m}·2),

* *See Plate* IX. for the cross-sec-

* Means of velocity-measurements at each depth.																	
Surface	3′	6′	12′	18′	24′	30′	36′	42′	48′	54′	60′	66′	72′	78′	84′	90′	102′
high water at Carrollton.																	
mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.
1·293	1·279	1·296	..	1·310	..	..	1·325	..	..	1·303	..	..	1·267	..	..	1·235	1·203
1·052	1·076	1·119	..	1·114	..	..	1·128	..	..	1·092	..	1·064	..	..	..	..	..
·878	·806	·861	..	·863	..	·883	·859	..	..	..	..	..	..	..	..	..	..
at Carrollton and Bâton-Rouge.																	
·590	..	·585	·592	·601	·591	·581	·580	·577	·569	·567	·556	·549	·530	·515	·500	..	..
·730	..	·739	·732	·724	·716	·705	·700	·687	·679	·676	·662	·647	·615	..	..	..	..
·727	..	·729	·728	·716	·713	·699	·684	·670	·652	·629	..	..	..	..	..	..	..

care from boats moored in the river, other experiments were made in less detail in on the Bayous Plaquemine and La Fourche.

Means of velocity-measurements at each depth.									
Surface	5′	10′	15′	20′	30′	40′	50′	60′	70′
sippi at Columbus and Vicksburg.									
mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.	mèt.
1·214	..	1·245	..	1·270	1·278	1·273	1·276	..	..
1·396	..	1·393	..	1·383	1·340	1·276	1·225	..	..
2·286	..	..	..	..	..	2·298	2·216	2·234	2·079
Plaquemine and La Fourche.									
1·981	1·987	1·935	1·920	1·835	..	..	..	..	..
·963	·984	·994	·981	·960	..	..	..	..	..

tion of the Mississippi at Columbus.

The results furnished by double floats are probably also subject to another source of error: the complete apparatus being in equilibrium in the mass of the fluid, the sunken float readily yields to the oblique movements which take place in the stream, and may be raised into higher strata; in which case, the tension of the cord suddenly ceasing, the surface-float becomes free, and takes the lead, thereby indicating too high a velocity. Though little noticeable at low velocities, this source of error must assume considerable importance in a rapid stream able to retain in suspension solid bodies denser than water. Double floats though more handy than the meter in large bodies of water, present therefore less certainty, and their use tends to hide the law of decrease of velocity by diminishing the parameter of the parabola. Let us collect then on to one Table, the elements of the parabola which Messrs. Humphreys and Abbot deduce by interpolation from the preceding experiments.

On inspection of this Table, we are at once struck by the smallness of the ratios $V \div u$ and $M \div u$; the former, which in the European experiments does not fall below 1·10, is reduced to 1·02, so that there is a difference not exceeding $\frac{1}{50}$ between the maximum and mean velocities, a difference altogether negligible in practice. As to the parameter $M \div u$ whose minimum was ·4 in the rivers of Europe, it falls down to ·15. Another and not less striking peculiarity is the unusual rise of the ratio a which reaches ·45 in the experiments at Carrollton, and ·5 in those at Columbus. Messrs. Humphreys and Abbot lay down indeed as a principle that the normal value is ·317, that is to say that in a regular stream whose surface is not affected by wind, the maximum velocity is always at $\frac{1}{3}$ of the depth*.

These results are almost in complete disagreement with the experiments above discussed; if this disagreement occurred only in the case of the special experiments on the Mississippi, it might be attributed to the exceptional conditions of this immense body of water: but they are also equally pronounced on the Bayous; and the American experimenters have obtained on these bodies of water, in all respects like our rivers in Europe, extremely low values (·16 to ·22) for the parameter $M \div u$.

* The general value of a, taking into account the effect of the wind, would be $a = {·}317 + {·}06 f$, f being a number proportional to the force of the wind: this number lying between 0 and 10, must be considered plus or minus, according as the wind blows from the down or up-stream direction. (*Report upon the Mississippi*, page 262).

Detail of Experiments.	Depth.	Elements of parabola $v = V - M(x - a)^2$ given by Messrs. Humphreys and Abbot			Elements of parabola in form $\frac{v}{u} = \frac{V}{u} - \frac{M}{u}(x - a)^2$	
		V	M	a	$V \div u$	$M \div u$
Mississippi Experiments.						
		mètres	mètres			
Carrollton (low water), ...	95′ to 100′ (29ᵐ to 30ᵐ·5),	·593	·173	·12	1·070	·312
Carrollton and Bâton-Rouge (low water), ..	75′ to 80′ (22·9 to 24·4),	·729	·190	·12	1·063	·277
,, ,, (low water), ..	55′ to 65′ (16·8 to 19·8),	·726	·191	·16	1·055	·278
Carrollton (high-water), ...	50′ to 55′ (15·3 to 16·8),	·878	·273	·40	1·029	·320
,, ,, ...	65′ to 70′ (19·8 to 21·3),	1·126	·267	·45	1·021	·242
,, ,, ...	105′ to 110′ (32·0 to 33·5),	1·311	·267	·30	1·026	·210
Columbus, ...	55′ to 75′ (16·8 to 22·9),	1·281	·242	·52	1·016	·192
Vicksburg, ...	45′ to 65′ (13·7 to 19·8),	1·395	·267	·10	1·049	·201
Vicksburg, ...	75′ (22·9)	2·310	·338	·20	1·026	·150
Experiments on Bayous.						
Bayou La Fourche, ...	27′ (8ᵐ·2),	·991	·218	·35	1·024	·225
Bayou Plaquemine, ...	27′ (8·2),	1·978	·306	·08	1·042	·161

This result is clearly in fault, and must throw doubt on the exactitude of the method used for velocity-measurement.

Messrs. Humphreys and Abbot assign to the parameter M the value $M = \sqrt{bU}$, U being the mean velocity of the whole cross-section, and b a coefficient varying with H, viz., $b = \cdot 284 \div \sqrt{H + \cdot 457}$. In a regular channel of great width, the ratio $M \div u$ would become, making $U = u$, and replacing b by its value,

$$\frac{M}{u} = \frac{\cdot 533}{\sqrt{u} \cdot \sqrt[4]{H + \cdot 457}}$$

whence result, by varying H and u, the following values :—

Value of H.	Values of M ÷ u for			
	$u = \cdot 5$	$u = 1\cdot 0$	$u = 1\cdot 5$	$u = 2\cdot 0$
1·	·686	·485	·396	·343
2·	·602	·426	·348	·301
5·	·493	·349	·285	·247
10·	·419	·297	·242	·210
20·	·356	·251	·205	·177
30·	·321	·227	·185	·160

The ratios above vary between very wide limits: it is impossible to make further comparison with the results of the formulæ (5), (6), as the American experiments do not show the values of I or $\sqrt{A}$. The results collected in the Tables of pages 68,69 are in fact the mean of a certain number of experiments made at various times, and it is impossible to assign to the constantly-varying slope of the river a corresponding mean value.

4°. Experiments of Mr. Robert Gordon on the Irrawaddi.

Experiments similar to those on the Mississippi have recently been made on the Irrawaddi by Mr. Robert Gordon, an English Engineer*: they may be compared with those of Messrs. Humphreys and Abbot, for in the lower part of its course the Irrawaddi almost equals the great American river in the size of its bed, and in the enormous volume of water which it discharges when in flood.† The experiments were made in 1872 and '73 at Saïktha, at the head of the delta formed by the numerous

* In a recently published memoir, "*Fragment containing a discussion of a new formula for the flow of water in open channels*, Milan, 1878," Mr. Gordon proposes a new formula for the discharge in a canal : this memoir mentions some data taken from the Irrawaddi experiments.

† The discharge of the river in flood rises at Saïktha to 40,000 cubic mètres per second, and the water level may rise 14 mètres above low level, (*see* the cross-section, *Plate* IX.)

mouths of the river. Mr. Gordon has most obligingly placed his field-books at my disposal, showing the data collected daily throughout a whole year, and has kindly authorized my taking extracts. I shall borrow from this vast collection of experiments still unpublished, some remarkable results which fall within the plan of this essay.

The velocities were measured as on the Mississippi by means of double floats traversing a space of 200 feet; but the cord used to connect the two floats was not nearly so thick; it was made of a very strong cord of ·001 to ·002 mètres thickness, used in the country for making nets; the lower float was placed in succession at 1, 2, 3, &c., mètres below the surface.

The observations having been carried on almost uninterruptedly for a long period, it was necessary—previous to all discussion—to classify them into several distinct groups according to the depth of water. These groups are four in number.

Low water, { Series 1°.—Experiments made whilst the river stood at 1′ to 3′ on the gauge at Saïktha.
Series 2°.—Experiments made whilst the river stood at 3′ to 5′.

High water, { Series 3°.—Experiments made whilst the river stood at 26′ to 30′ on the gauge at Saïktha.
Series 4°.—Experiments made whilst the river stood at 30′ to 35′.

This primary classification once made, the number of verticals on which the experiments were made was still so great in each series, that it was necessary to subdivide the cross-section of the stream into subsections: these subsections,—arranged so as not to include very different depths,—are four in number for low water, and six for high water; they are shown on the cross-section of the river (*Plate* IX.)*; a separate mean has been calculated for each of them, by grouping together all the velocity-measurements in the subsection; the points of observation on each vertical, being regularly spaced at equal intervals of 1 mètre from the surface downwards, do not subdivide the verticals into proportional parts; it has been necessary to find by interpolation from the observed velocities, the velocities at $\frac{1}{10}$, $\frac{2}{10}$, $\frac{3}{10}$, ... $\frac{9}{10}$ of the depth, and then take out the mean of all the values so interpolated for the whole of each subsection. The Table below shows in an abridged form the results of these laborious calculations carried out for more than 500 verticals.

* A shaded rectangle corresponds on the figure to each subsection: the (horizontal) length of this rectangle shows the limits between which the experiments were made, the vertical height shows the limit through which the water level varied during the course of those experiments. In order to avoid fractions, it has been thought right to preserve English measures on this cross-section: thus the ordinates are spaced at 100′ (about 30m.48).

		Mean depth of water at Saïktha gauge	Depth.		Mean of Velocity-Measurements.									
			Limits in feet	Mean in mètres	Surface	·1 H	·2 H	·3 H	·4 H	·5 H	·6 H	·7 H	·8 H	·9 H
Saïktha Experiments, low water.														
		mètres	feet	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres
Series 1.	Section No. 1.—Mean of 23 verticals,	·59	18—23	6·12	·580	·578	·573	·565	·558	·550	·542	·530	·507	·476
	" 2.— " 46 "	·54	23—30	7·77	·615	·609	·600	·589	·581	·573	·563	·545	·522	·501
	" 3.— " 26 "	·53	27—33	9·13	·561	·548	·543	·532	·522	·504	·485	·472	463	·443
	" 4.— " 31 "	·58	32—40	11·23	·517	·525	·518	·507	·496	·483	·465	·455	·435	·396
Series 2.	Section No. 1.—Mean of 27 verticals,	1·14	18—24	6·26	·645	·639	·631	·623	·612	·604	·600	·587	·567	·530
	" 2.— " 22 "	1·03	25—29	8·31	·718	·714	·705	·692	·681	·670	·643	·625	·600	·564
	" 3.— " 11 "	1·20	29—34	9·45	·664	·651	·637	·620	·600	·597	·579	·577	·565	·508
	" 4.— " 24 "	1·05	37—40	11·98	·606	·600	·588	·575	·550	·543	·530	·506	·482	·440
Saïktha Experiments, high water.														
Series 3.	Section No. 1.—Mean of 26 verticals,	8·74	18—22	6·07	1·252	1·238	1·222	1·203	1·165	1·128	1·116	1·091	1·063	1·032
	" 2.— " 15 "	8·81	25—30	8·23	1·341	1·362	1·333	1·297	1·261	1·260	1·215	1·180	1·154	1·101
	" 3.— " 17 "	8·67	32—40	10·83	1·394	1·387	1·376	1·357	1·303	1·248	1·254	1·246	1·184	1·122
	" 4.— " 20 "	8·71	41—47	13·44	1·593	1·563	1·553	1·516	1·476	1·505	1·478	1·443	1·481	1·407
	" 5.— " 34 "	8·70	46—54	15·53	1·892	1·864	1·860	1·836	1·793	1·759	1·766	1·798	1·802	1·750
	" 6.— " 29 "	8·72	53—65	17·68	1·775	1·762	1·728	1·693	1·683	1·667	1·692	1·697	1·701	1·687
Series 4.	Section No. 1.—Mean of 41 verticals,	9·82	20—25	6·88	1·385	1·362	1·350	1·363	1·320	1·301	1·269	1·226	1·187	1·153
	" 2.— " 15 "	9·75	26—32	8·72	1·481	1·476	1·485	1·438	1·382	1·381	1·362	1·295	1·268	1·240
	" 3.— " 14 "	9·92	33—42	11·35	1·608	1·608	1·550	1·517	1·543	1·450	1·476	1·475	1·390	1·342
	" 4.— " 25 "	9·73	43—51	14·36	1·741	1·728	1·730	1·661	1·653	1·622	1·641	1·606	1·595	1·572
	" 5.— " 31 "	9·88	47—64	16·77	2·101	2·098	2·064	2·040	1·987	1·984	1·982	2·014	1·994	2·007
	" 6.— " 32 "	9·97	60—70	20·19	1·990	2·003	1·961	1·936	1·947	1·954	1·969	1·950	1·984	2·005

A mere glance at the preceding data shows at once a decided discrepancy between the Irrawaddi and Mississippi experiments; the maximum velocity which Messrs. Humphreys and Abbot place always at a great depth is in these, with rare exceptions, at the surface itself. By examining the decrease of velocity from the surface downwards, it is seen that at low water, (Series Nos. 1, 2,) this decrease is decidedly more marked than in the Mississippi experiments at Carrollton. At high water (Series Nos. 3 and 4), a singular anomaly appears; whilst the three first sections of each series furnish results like those at low water, the decrease of velocity diminishes continuously at the other sections, and finally disappears altogether at the last, where the velocity reaches 2 mètres per second at the bottom as at the surface. This strange result is evidently inadmissible, and its explanation must be sought in a source of error inherent in the mode of experiment used: this cause already alluded to above, is simply—in my opinion—the displacement of the lower float, raised by the tumultuous motion of the fluid into strata higher than those in which it is supposed to move; nearly nil at low water, this disturbing influence must act with increasing intensity when the velocity of the lower strata of the stream becomes high enough to hold in suspension solid particles of a density equal to that of the floats.

To proceed to a more detailed discussion of the velocities measured on the Irrawaddi and Mississippi, it is necessary to group them, so as to collect together the experiments in which the velocities differ slightly, and to form means in which the influence of experimental anomalies shall be sufficiently got rid of.

After finding the difference between the maximum velocity and the velocity at $\frac{9}{10}$ of the depth, it is easy to see that this difference is proportionately larger in the Irrawaddi experiments: this peculiarity will appear more clearly by transforming the preceding data, so as to show the mutual ratios of the velocities. Take the fundamental equation (1), make $a = 0$, and divide both members by V, whence

$$\frac{v}{V} = 1 - \frac{M}{V} x^2$$

But we have (*see* (6)) made $M = 20\, u \sqrt{A}$, and we have on the other hand (*see* (2)) $u = V - \frac{1}{3} M$, whence results

$$\frac{M}{V} = \frac{20 \sqrt{A}}{1 + \frac{1}{3}\, 20 \sqrt{A}}$$

	Detail of Series of Experiments.	Depths. Limits in feet.	Depths. Mean in mètres.	Mean of Velocity-Measurements. Surface	·1 H	·2 H	·3 H	·4 H	·5 H	·6 H	·7 H	·8 H	·9 H	Remarks.
	Irrawaddi.	feet	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres	mètres	
Low Water.	Series No. 1. Mean of 126 verticals,	18—40	8·60	·573	·570	·563	·553	·543	·532	·519	·505	·486	·459	Max. velocity at surface.
	Series No. 2. Mean of 84 verticals,	18—40	8·85	·655	·649	·639	·627	·611	·603	·589	·573	·551	·510	
	Series Nos. 1, 2. General Mean of the former (210 verticals), ..	18—40	8·70	·606	·602	·593	·582	·571	·561	·547	·532	·512	·479	
High Water.	Series No. 3. Sections Nos. 1, 2, 3. Mean of 58 verticals, ...	18—40	8·05	1·317	1·314	1·296	1·272	1·230	1·198	1·182	1·160	1·122	1·076	Ditto.
	Series No. 4. Sections Nos. 1, 2, 3. Mean of 70 verticals, ...	20—42	8·15	1·450	1·436	1·419	1·393	1·378	1·348	1·330	1·291	1·245	1·210	
	Series Nos 3, 4. Means of above Sections 1, 2, 3, (128 verticals).	18—42	8·10	1·390	1·380	1·363	1·338	1·311	1·280	1·263	1·231	1·189	1·149	
	Series Nos. 3, 4. Section No. 4. Mean of 45 verticals, ...	41—51	13·95	1·675	1·655	1·651	1·597	1·574	1·570	1·569	1·534	1·521	1·499	Ditto.
	Series No. 3. Sections Nos. 5, 6. Mean of 63 verticals, ...	46—65	16·55	1·838	1·817	1·799	1·770	1·742	1·716	1·732	1·752	1·756	1·724	
	Series No. 4. Sections Nos. 5, 6. Mean of 63 verticals, ...	47—70	18·50	2·045	2·050	2·012	1·987	1·967	1·969	1·975	1·981	1·989	2·006	
	Mississippi.													
Low Water.	General Mean of experiments at Carrollton and Bâton-Rouge, (80 verticals), ...	55—100	22·90	·686	·689	685	·676	·671	·659	·646	·633	·613	·587	$a = ·15$
High Water.	General Mean of experiments at Carrollton, (142 verticals), ..	55—110	26·20	1·136	1·151	1·164	1·173	1·172	1·167	1·152	1·133	1·113	1·087	$a = ·35$
	Experiments at Columbus. (Mean of 52 verticals), ...	55—75	19·80	1·214	1·234	1·253	1·269	1·275	1·277	1·276	1·276	..	..	$a = ·52$
	Experiments at Vicksburg. (Mean of 20 verticals), ...	45—65	17·40	1·396	1·394	1·392	1·386	1·374	1·350	1·320	1·286	1·256	1·228	$a = ·10$
	Experiments at Vicksburg. (Mean of 3 verticals), ...	75	22·90	2·286	..	..	..	..	2·298	2·257	2·221	2·234	2·118	$a = ·20$

and the equation of the parabola becomes under this form,

$$\frac{v}{V} = 1 - \frac{20\sqrt{A}}{1 + \frac{1}{8}\,20\sqrt{A}}\,x^2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8).$$

The hydraulic mean depth varies in Mr. Gordon's experiments, from 5·5 to 13 mètres, and assuming that the formula $A = \cdot 00028\left(1 + \frac{1\cdot 25}{R}\right)$ deduced by me from the data collected from European rivers, is applicable to the Irrawaddi, the corresponding values of $\sqrt{A}$ will be ·0175 and ·0185; introducing the mean, viz., $\sqrt{A} = \cdot 018$ into formula (8), it reduces to

$$\frac{v}{V} = 1 - \cdot 32\,x^2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9).$$

This formula would assign to the ratio $v \div V$ the following values :—

Values of											
x	0	·1	·2	·3	·4	·5	·6	·7	·8	·9
$v \div V$	1·000	·997	·987	·971	·949	·920	·885	·843	·795	·741

Let us return then to the Table of page 76, and divide all the velocities of each series by V.

The comparison of the above results will be more easily done by help of a graphic representation; let us take as ordinates the depth x, and as abscissæ the ratios $v \div V$, and plot for each group of means the points corresponding to the values $v \div V$, as well as the parabola represented by Eq. (9), (*see Plate* X., *Fig.* 5, 6); an examination of these curves suggests the following remarks :—

1°. Those of the Irrawaddi, except the last, (No. 5, high velocities of 2 mètres per second,) agree sensibly with the parabolic theory as far as the point corresponding to mid-depth ($x = \cdot 5$): beyond this point a discrepancy appears, scarcely noticeable in the low water experiments: it is declared more markedly the more the velocities increase; in the two last (Nos. 4, 5) the curvature is even reversed beyond the ordinate of $x = \cdot 6$, so that the velocities begin to increase again downwards and become near the bottom almost equal to the surface-velocities.

2°. The Mississippi curves present quite another appearance. The low water curve (No. 1) recalls the corresponding Irrawaddi curve, with the single exception that the value of the parameter is markedly less. It is just the same with the curve No. 4 (of the Vicksburg experiments) which may be compared with Nos. 2, 3 of the Irrawaddi curves. As to the other three, they differ entirely because they suppose the maximum velocity

	Detail of Experiments.	Mean Depth in mètres	Maximum velocity.	Ratios $v \div V$ of velocities v to maximum velocity V.										Remarks.
				Surface	·1 H	·2 H	·3 H	·4 H	·5 H	·6 H	7 H	·8 H	·9 H	
	Irrawaddi.													
		mètres	mètres											
Low Water.	General mean of Series Nos. 1, 2. 210 verticals, ...	8·70	·606	1·000	·993	·979	·960	·942	·926	·903	·878	·845	·790	Max. velocity at surface.
High Water. Series 3, 4.	Mean of Sections Nos. 1, 2, 3 of both Series. 128 verticals, ..	8·10	1·390	1·000	·993	·981	·963	·943	·921	·909	·886	·855	·827	
	Mean of Section No. 4 of both Series. 45 verticals, ...	13·95	1·675	1·000	·988	·986	·953	·940	·937	·937	·916	·908	·895	
	Mean of Sections Nos. 5, 6 of Series No. 3. 63 verticals, ...	16·55	1·838	1·000	·989	·979	·963	·948	·934	·941	·953	·955	·938	
	Mean of Sections Nos. 5, 6 of Series No. 4. 63 verticals, ..	18·50	2·045	1·000	1·002	·984	·972	·961	·963	·966	·969	·973	·981	
	Mississippi.													
Low Water.	General Mean of experiments at Carrollton and Bâton-Rouge. 80 verticals, ...	22·90	·689	·996	1·000	·994	·981	·974	·956	·938	·919	·890	·852	$a = ·15$
High Water.	General Mean of Carrollton experiments. 142 verticals, ..	26·20	1·173	·968	·981	·992	1·000	·999	·995	·982	·966	·949	·927	$a = ·35$
	Experiments at Columbus. Mean of 52 verticals, ...	19·80	1·277	·951	·966	·981	·994	·998	1·000	·999	·999	..	..	$a = ·52$
	Experiments at Vicksburg. Mean of 20 verticals, ...	17·40	1·396	1·000	·990	·997	·993	·984	·967	·946	·920	·900	·880	$a = ·10$
	Experiments at Vicksburg. Mean of 3 verticals, ...	22·90	2·298	·995	..	..	..	..	1·000	·982	·966	·972	·922	$a = ·20$

at a considerable depth. The curves Nos. 3 and 5 have however this common characteristic along with the corresponding Irrawaddi curves, that the velocities are almost as high at the bottom as at the surface, but they do not preserve, as the latter do, a trace of the parabolic law in the higher state of the stream.

The anomalies which this graphic representation throws into relief, appear to me to be explained by the mode of experiment used. In the first place the acceleration of the lower float, increasing on the one hand with the depth, and on the other with the thickness of the cord, ought to be much more marked in the Mississippi experiments than in those of the Irrawaddi, in consequence of the greater depth of the river, and of the considerable size of cord used to connect the floats. Thus the experiments of Messrs. Humphreys and Abbot diverge much more than those of Mr. Gordon from the parabolic law given by the European experiments. As to the displacement of the lower float at high velocities, it constitutes—as above shown—a second source of error which cannot be got rid of, and whose influence is shown in all these experiments when the velocities reach 1·5 mètre per second; yet Mr. Gordon's curves permit the parabolic decrease to be seen even in this last case throughout the third or half-depth, whilst those of Messrs. Humphreys and Abbot present a singular diversity, in which it is difficult to see any well defined law: it cannot in fact be explained otherwise than by experimental error how the maximum velocity is sometimes found to fall below mid-depth.

Summary of the above experiments.

Let us examine now the diverse results which we have rapidly reviewed. The discussion of the experiments on the small scale shows incontrovertibly that the parameter (M) of the velocity-parabola cannot remain constant when the maximum is below the surface; it must in this case increase with a, and the experimental data are closely satisfied by replacing M by $M \div (1-a)^2$. Other analogous experiments might have been brought into this discussion: they would not introduce any new element, and I shall confine myself here to citing one, of a quite special character, in which again the necessity of increasing the parameter with a is clearly seen.

With the view of studying velocity-distribution in a rectangular channel, Mr. Darcy had constructed in 1857 a rectangular pipe of ·8 mètre horizontal width by ·5 mètre height*; by sending different volumes of water through it, it was proved that the velocities were distributed quite regularly round the centre, and that the law of this distribution was in no way dependent on their absolute values, the ratio $v \div U$ of the velocity v at a given point of the section to the mean velocity U of the whole section remaining constant, whatever the volume discharged might be; the coefficient $RI \div U^2$ was also likewise constant and equal to ·000275. If we suppose the cross-section of the pipe cut in two equal parts by a horizontal plane traversing the middle point of its height (2H), each of these halves in which the velocities are symmetrically arranged, may be compared with a rectangular channel of depth H. The decrease of the velocities on the central vertical of this channel would follow the parabolic law as shown below:—

Velocities measured,	at centre of the pipe, ...	$v = 1{\cdot}176$ U
	at ·11 mètre, or ·44 H below, ...	$v = 1{\cdot}119$ U
	at ·22 mètre, or ·88 H below, ...	$v = 0{\cdot}891$ U

After experimenting on the pipe, it was converted into an open channel by removing its top, and a volume of water was passed down it such that the depth of the stream was precisely equal to H. The section of this stream being the same as that of the half-pipe above considered, we actually found nearly the same mean velocity U and same coefficient $RI \div U^2$ as in the case of the pipe for a like value of I: the velocity-distribution however, was no longer the same.

Velocities measured,	at ·03 mètre, or	·12 H	below the surface, ..	$v = 1{\cdot}245$ U
	at ·11 „	·44 H	„ ..	$v = 1{\cdot}180$ U
	at ·17 „	·68 H	„ ..	$v = 1{\cdot}072$ U
	at ·22 „	·88 H	„ ..	$v = {\cdot}911$ U

Here again these values satisfy the equation of a parabola, but the vertex instead of being at the surface, is at about $\frac{1}{6}$ of the depth; the ratio 1·18 which in the case of the closed pipe coresponded to the centre, occurs at the depth ·44 H; as to the velocity near the bottom, it was not sensibly changed; the parameter must therefore be increased in a considerable proportion. Let us then test by these two examples the formula

$$\frac{v}{u} = \frac{V}{u} - \frac{20\sqrt{A}}{(1-a)^2}(x-a)^2.$$

* For these experiments, *see Recherches Hydrauliques*, 3rd part, Chap. II.

To proceed with this trial, it must be observed that u denotes the mean velocity on the central vertical, which is greater than U the mean for the whole section; there easily results for the closed pipe $u = 1{\cdot}058$ U, and for the open channel $u = 1{\cdot}114$ U; substituting, and making $a = {\cdot}15$, $A = {\cdot}000275$, the above equation becomes

$$\text{For the closed pipe,} \quad \frac{v}{U} = 1{\cdot}175 - {\cdot}351\, x^2.$$

$$\text{For the open channel,} \quad \frac{v}{U} = 1{\cdot}220 - {\cdot}512\, (x - {\cdot}15)^2,$$

and applying it to the two experiments, we have,—

Closed Pipe.			Open Channel.		
Distance from centre.	Value of $u \div$ U.		Depths.	Value of $u \div$ U.	
	by experiment.	by formula.		by experiment.	by formula.
0	1·176	1·175	·12 H	1·245	1·220
·44 H	1·119	1·107	·44 H	1·180	1·177
			·68 H	1·072	1·076
·88 H	·891	·903	·88 H	·911	·947

The agreement is as close as could be wished*. I repeated in 1859 these comparative experiments on a smaller pipe; the results being quite similar, it is unnecessary to record them here.

Let us pass to the experiments on large bodies of water. The parabolic law is clearly shown in those which were made in Europe by means of a meter; the increase of parameter with a was even more marked than in the artificial channels, and a rapid decrease of velocity is often shown on nearing the bottom. This peculiarity is especially marked on the Saône, where the meter was placed some centimètres from the river-bed. Nevertheless the motion of the instrument being clearly hindered in this case, it may be admitted with great probability that the velocities so obtained are too low.

But if we now consider the great series of experiments made by use of double floats on the Mississippi and Irrawaddi, we are face to face with a

* This agreement could be made closer for the open channel, by increasing the parameter of the parabola a little more.

strange diversity of results; on the Irrawaddi we recognize pretty nearly the parabola of the European streams, so long as the velocities do not exceed a certain limit; but beyond that we see the parabola flattening out more and more low down, and in the case of the high velocities of 2 mètres per second measured in the deepest part of the stream, all curvature finally disappears: as to the maximum velocity, it is commonly at the surface. On the Mississippi the disagreement of the results, which have almost nothing in common with the European experiments, is more striking; the value of the parameter is much less, and the maximum velocity is always much below the surface.

The use of double floats would certainly have the effect of concealing the decrease of velocity, and an attempt was made above to explain how this mode of experiment might even be completely at fault in the deepest strata of a rapid stream. However it must be admitted that these explanations are not sufficient to account for the disagreement which the American experiments show, not only with the European ones, but even among each other; in fact they give for a:

Experiments	at Carrollton and Bâton-Rouge, low water, ...	·12 to ·16
„	at Carrollton, high water, ...	·30 to ·45
„	at Columbus, ...	·52
„	at Vicksburg, ...	·10 to ·20

May not this discordance be partly explained by the fact that the Tables from which Messrs. Humphreys and Abbot deduce the equations of their parabolas, include in their means a medley of too heterogeneous data?

The 39 verticals on which work was done at Carrollton and Bâton Rouge belong to five distinct sections; as to the experiments at Columbus which give $a = \cdot 52$ they were certainly made at one section, but they correspond to such different states of the river, that the velocities varied there from ·6 mètre to more than 2 mètres per second. By grouping such dissimilar elements into one mean, there is a likelihood of introducing some confusion into the results, and especially of rendering the position of the maximum velocity very uncertain.

The Irrawaddi experiments—by their great number and regular arrangement at a single section, are much better adapted to a systematic classification, and admit of groups being formed including only perfectly comparable data; they form on the other hand a sort of link between the European experiments with which they agree in many points, and those of Messrs. Humphreys and Abbot; but though they show like the latter the marks of the procedure followed in velocity-measurement, they do not nevertheless leave any uncertainty in the position of the maximum which they place near the surface.

The results obtained by Mr. Gordon disagree on yet another important point with those of the American experimenters; now Messrs. Humphreys and Abbot make the coefficient $A = RI \div U^2$ depend almost exclusively on the slope I; their formula, according to which A would increase and decrease with I without being sensibly influenced by the change of hydraulic mean depth R, leads in the case of slight slopes to values of A much less than those hitherto received. Mr. Gordon found on the Irrawaddi in flood at Saïktha values of A comprised—as on the European rivers—between ·0003 and ·0004, and he has further shown that for small values of R, A increased gradually as R decreased, although the slope itself decreased considerably, a result agreeing with the European experiments and quite opposed to the Mississippi ones.

I shall conclude by showing by some numerical comparisons in what proportions the formulæ to which I have been led, make the velocities vary ultimately on one vertical: my aim was to show that the parameter must increase with A and a, and to fulfil this double condition, I have thrown the equation of the velocity-parabola into the form

$$\frac{v}{u} = \frac{V}{u} - 20\sqrt{A}\left(\frac{x-a}{1-a}\right)^2$$

The mean velocity u not being immediately given by direct observation like V, it will be more convenient to replace the ratios $\frac{v}{u}$ by $\frac{v}{V}$, as was done before when discussing the Irrawaddi experiments; dividing both sides by $V \div u$, the above equation becomes

$$\frac{20\sqrt{A}}{\frac{V}{u}(1-a)^2}(x-a)^2$$

Again by (7)

$$\frac{V}{u} = 1 + \frac{20\sqrt{A}}{(1-a)^2}\left(\tfrac{1}{3} - a + a^2\right).$$

Let us apply these formulæ to some of the experiments, of which the elements have been given above, without however returning to those of the Mississippi and Irrawaddi, which have already been the object of special discussion; the latter would not indeed furnish the numerical data necessary to the comparison now proposed.

Detail of Experiments.		Value of $\sqrt{A}$	Value of a	Value of $V \div u$	Equation of theoretical parabola.	Bottom-velocity (theoretical).
Experiments on small scale.						
Smooth sides, &c., of plaster.—	Series No. 55.—Experiment No. 1,	·0131	zero.	1·087	$\frac{v}{V} = 1 - ·241\ x^2$	$\frac{v_1}{V} = ·759$
Slightly rough sides, &c., of plank covered with strips, at ·01 mètre apart.—	,, ,, 61.— ,, ,, 4,	·0184	·30	1·092	$= 1 - ·688\ (x - ·30)^2$	$= ·663$
,, ,, ,,	,, ,, 62.— ,, ,, 4,	·0191	zero.	1·127	$= 1 - ·339\ x^2$	$= ·661$
Sides, &c., lined with coarse gravel.—	,, ,, 57.— ,, ,, 1,	·0257	·25	1·133	$= 1 - ·307\ (x - ·25)^2$	$= ·546$
Sides, &c., of plank covered with strips at ·05 mètre apart.— ..	,, ,, 65.— ,, ,, 3,	·0287	zero.	1·191	$= 1 - ·482\ x^2$	$= ·518$
Experiments in Europe on great bodies of water.						
Saône.—	Mean of Experiments, Nos. 2, 3, 4, ...	·0204	·15	1·116	$\frac{v}{V} = 1 - ·505\ (x - ·15)^2$	$\frac{v_1}{V} = ·635$
Seine.—	Mean of verticals, Nos. 10 to 13, and 19 to 22, ..	·0203	zero.	1·135	$= 1 - ·358\ x^2$	$= ·642$
Garonne.—	Experiment in 1841, ...	·0190	·20	1·103	$= 1 - ·538\ (x - ·20)^2$	$= ·656$
Garonne.—	Experiment in 1845, ...	·0200	zero.	1·133	$= 1 - ·353\ x^2$	$= ·647$
Rhine, at Basle.	.. ..	·0260	zero.	1·173	$= 1 - ·443\ x^2$	$= ·557$

Figs. 7, 8 of *Plate* X. exhibit the above results according to the mode of graphic representation used for the Irrawaddi experiments. The parabolic theories are there shown by the continuous curves having for abscissæ the ratios, $v \div V$, and for ordinates the depths x; to the experimental values of $v \div V$ correspond the isolated points which do not generally differ from it markedly.

The extreme difference of the velocities, *i. e.*, the difference $(V - v_1)$ between the maximum velocity V and that at the bed (v_1) varies in artificial canals from $\frac{1}{4}$ V to $\frac{1}{2}$ V, and increases with the degree of roughness of the sides: this should be remarked, because it is to the resistance of the sides,—measured by the coefficient $\sqrt{A}$—that the unequal distribution of velocities is due. In natural channels this difference is about $\frac{1}{3}$ V. The experiment on the Rhine at Basle must be excepted: there are united in this remarkable experiment a large section and a high slope, very rare conditions which cannot coexist except in consequence of the unusual resistance of the bed which is covered with large boulders: thus the difference of velocities is here seen to increase and reach nearly $\frac{1}{2}$ V.

When the maximum velocity is not at the surface, the difference $(V - v_1)$ does not decrease, and the parameter becomes necessarily greater. This increase does not suggest itself so naturally to the imagination as that due to increase of resistance in the sides; but it appears very clearly by inspection of the figure, and it is clear that we cannot arrive at a representation of the phenomena under the hypothesis of constant parameter.

DIJON, 10th *February*, 1875.

Note by Translator.

The author of this Paper attributes principally to experimental error (inherent in the use of the "Double Float") the great depth of the line of maximum velocity in some of the Mississippi Experiments.

To the translator it appears on the contrary that the depression of the line of maximum velocity is an excellent proof of the fair correctness of the results from the "Double Float,"—when due care is taken to reduce the size of the surface-float and connecting cord to minimum dimensions—as it shows that the sunken Float is able to control the movement of the whole.

No. CCXVIII.

FACING FOR RACQUET COURT WALLS.

By Major G. Merewether, R.E., *Exec. Engineer, Bombay Defences.*

In 1869, a Racquet Court and a Fives Court were built, back to back, in the Morley Hall (Soldiers' Institute) Grounds at Colaba, the partition wall between them forming the front wall of each.

This wall (like the side and back walls) was faced with ordinary lime plaster, a considerable portion of which very soon gave way, and in July 1870, an estimate having been called for by Government, was submitted, provision being made for removing the facing of the entire Racquet Court, and substituting for it finely dressed cut-stone ; and at the same time an opinion was expressed that an equally durable and smooth surface might be obtained by the use of Portland cement properly used.

This estimate amounted to Rs. 16,246, which being considered too much to spend on the work, a revised estimate, amounting to Rs. 2,289, was submitted in December 1870.

In this estimate, provision was made for substituting cut-stone in the front wall only, and merely to a height of 25 feet from the floor, or over an area of 1,000 square feet, this being the part which had suffered.

A doubt was at the same time expressed as to whether the cut-stone would be a success, and it was strongly recommended to adopt instead of it Portland cement plaster, very carefully prepared, and applied over the same area, (the lime plaster having been removed, and the joints in the rubble masonry backing carefully raked out, so as to afford a good hold for the cement,) and it was pointed out that it would cost a mere trifle (estimated at Rs. 278) compared with the expenditure on cut-stone.

Authority to try Portland cement plaster was then given, and in February 1871, the work was carried out according to the following directions, being those contained in the general description of the estimate.

"The walls of the Racquet Court are now plastered with ordinary lime. The lower portion, 25 feet high, of the front wall, has suffered much from the blows of the Racquet balls, and in some places the plaster has peeled off. It is proposed to try whether by using Portland cement applied with great care, a better result may not be attained, at a cost very much less than that of cut-stone, which will otherwise probably have to be used.

"The Portland cement to be that of Messrs. Knight, Bevan and Sturge, or of the Wouldham Cement Company, strength being the great object, and quick setting of no importance. The cement to be thoroughly mixed with twice its quantity by measure, of clean, sharp, sweet sand, or should sweet river sand not be procurable, sea sand carefully washed in fresh water. With this, hemp in the proportion of 1 lb. to each three cubic feet of the plaster, and cut in short lengths, to be mixed. Sweet water only to be used in the mixing. The entire surface to be laid on in one day to within half inch of the intended face, to be then thoroughly consolidated by means of the *thapki*, and before closing the work for the night, the whole area is to be intersected by diagonal lines drawn with trowels to a depth of about quarter inch, and crossing each other at a distance of about two inches, so as to form a rough surface to which the remainder may adhere. Then on the following day the remaining portion of the plaster to be applied, and then consolidated by means of the *thapki*, care being taken to keep it as nearly in one vertical plane as possible, the whole being finished off on the same day with a very thin coating of plaster, in which the sand to be particularly fine, to bring the whole to a smooth surface."

The work, the cost of which was Rs. 280, was done necessarily at the very worst time of year, the hot weather just coming on, but care was taken to keep the work moist for some time after its completion, and it has been a great success, a very fair facing having thus been provided, which has been in constant use ever since; the total cost of repairs to the plaster during the five and a half years, having been Rs. 2-12-6 only, and the wall being now, with the exception of one small place, which requires an expenditure of about 1 Re., apparently nearly as good as when the plaster was first applied in February 1871.

The side and rear walls, and the remainder of the front wall, are still of lime plaster, and have stood well.

It is thought that the experience thus gained may perhaps be of use in reducing the cost of Fives or Racquet Courts elsewhere.

So far as Fives balls are concerned, plaster made with Bombay lime and properly applied, stands their blows very well, but this may not be so at stations where the lime is not of such good quality.

G. M.

BOMBAY DEFENCES OFFICE,
6th July, 1876.

No. CCXIX.

RIVER-TRAINING OF THE INDUS AT SHAH JAMAL.

[*Vide* Plates XI., XII., XIII. and XIV.]

BY GRIFFIN W. VYSE, ESQ., *Assoc. Inst.* C.E., F.R.G.S., *&c., Exec. Engineer, Irrigation Branch, P. W. D.*

THIS paper treats of the measures which were adopted in the year 1876, to protect the right bank of the River Indus at Shah Jamál in the vicinity of the head of the Dhundi Canal, by diverting the main stream into a new channel. As the measures adopted were inexpensive, and at the same time thoroughly successful, a brief record of the operations may prove useful to the members of the Engineering profession in this country, in which similar works in rivers of the same nature as the Indus are constantly required in connection with bridges, weirs, canal heads, &c.

Few rivers in India, or perhaps in the world, have more variable floods, shifting streams, and less stable channels, than the Indus in its long course from the mountains to the sea.

There is no single reach of the main stream of this river which is straight for a thousand feet. That is to say, if its banks do not curve and twist every two or three hundred feet, its stream will rebound from left bank to right in the most persistent manner possible; and it follows this law for many hundreds of miles through the Sind country. What is very noteworthy, when the river is thus acting, is the variable way in which it discards the silt on the side it regurgitates, erosion and retrogression of level going on where it impinges. This action is always going on, and it is only by a careful study of its contortions and swaying nature, that the Engineer is enabled, by using the valuable agency of its silt deposit, to succeed in diverting the main body of the Indus as has been done at Shah Jamál.

That great hydraulic Engineer, Frisi, in speaking of the erosion of rivers of the nature of the Indus says, "if a stream even when enclosed "between parallel banks, begins to make erosions on any part whether "because the ground has there less tenacity and consistence, or the force "of the water is there increased by the repercussions of the parts above, "it will be the *points* and *angles* of the places corroded that will be first "overthrown, because those parts present the least resistance, and there the force and impetuosity of the current are the greatest." Guglielmini has treated this subject at great length in his sixth chapter on the "Nature of Rivers."

Thus the whole erosion will, in a short time, become one continued curve, and the thread of the stream,—(as to be seen in *all* Punjab rivers,—) flying off from this side, will go across and batter the opposite shore; and in the constant renewal of this same play, when an erosion has been made on the right bank of the river, another will be made on the left, and then another lower down on the right, till in this manner the whole river bank will become a continuation of arcs alternately concave and convex, and as the strength of the stream progressively lessens in proportion as the angle of the current with the corroded shore becomes more acute, the obliquity of the thread of the stream, impelled and repelled, becoming greater as the concavity of each erosion is enlarged, it will so happen that the force will at last become equal to the resistance, and each erosion will have its limit, which might be ascertained, if the laws of the force of the water and of the resistance of the ground were known. It may in general be asserted, that a sandy shore will yield more easily than one of loam, and that the erosions will be so much the greater as the current of the river shall strike the shore more directly.

Hence it is, that in some places, when erosions take place, Engineers are accustomed to throw back the embankments, and to wait until the erosion has reached its limit. In other places, the high perpendicular corroded bank is sloped off so as to present an inclined plane to the stream wherever it attempts to undermine it; but in most cases the encroachments must be promptly checked and their progress effectually prevented. Various defences, on a large and small scale, have been invented for this purpose.

The bays, so common along the soft shores of the Indus, are due to the action of whirlpools, which eat terribly into banks, scour the bed and change the course of the river far more than the high floods, where the river impinges, and the channel is at all confined the danger is considerably increased, particularly where the banks are baked, and broken up in sections and caked from the fierce heat, when great masses fall over with a loud report into the river. *Whirlpools can be stopped or checked* by turning the current some distance above their influence. In some cases half a mile up stream is not too far off to commence operations, and on one occasion we had to work a mile of running water before we managed to check an unusually powerful whirlpool.

Whirlpools are caused by retrogression of level, backward, or underground flow, cross or double currents meeting, sometimes by a sharp spur jutting out into the stream and bringing about an increased velocity at the point of contact with the main stream. The sand along the worst reach of Shah Jamál was of a very friable nature, but in certain sections of the higher sand embankments on the Sheru and Muzuffergurh ghât side, where the whirlpools were continually showing themselves, and where the erosion had been most actively at work, the accumulated deposit of last year, where it was some feet in depth, was unlike the other sand of the opposite shore being firm, hard and compact. Each freshet or flood, seemed to have brought down an entirely different stratum of deposit—here and there were intercepted veins of clay, varying in depth, color and solidity, not always lying parallel, but twisting, curving and bending, occasionally showing sharp dips and angles from the other lines, but all finally meeting towards a centre. I attribute such formation to the action of whirlpools, which have gradually spent themselves out. I need hardly say that to attempt to check the erosive action of whirlpools by throwing masses of brushwood, or bags of stones, or weeds into the middle of them, is utterly useless, producing no good results, but tends to increase the scour, and the power of the whirl. I believe small ones have been stopped by such means, but such a theory does not hold good with regard to the larger ones, and in some cases I know how disastrous have been the results in attempting it.

Famiano Michelini, in his "Treatise on the Direction of Rivers," is the first author who has written on the defences that might be opposed to waters, although he has not formed a correct view of the pressure, which, even in standing waters, arises simply from the depth. Barratieri in treating of spurs, has laid down no rules on the mode of placing them:

he merely takes it for granted that they ought to be fixed where the corrosion is the deepest, whereas on the contrary, it is easy to see, *that one ought to begin to turn off the current at the very edge of the erosion*, and that the spurs fixed lower down should be so placed, and *at such proportional distances, that they might mutually support, and be supported by each other*. Guglielmini and Zendrini have treated this subject more thoroughly and accurately.

But the science of hydraulics may be said to be still in its infancy, and no precise rules, based on incontrovertible theory and expressed in perfect mathematical formulæ, can guide the Engineer in determining the position, direction, form, and dimensions of spurs, or other contrivances for protecting the banks and guiding the currents of such a river as the Indus.

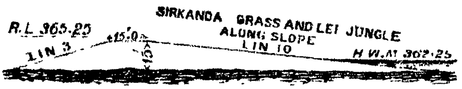
Reasoning and experience however, seem to show that the most advantageous direction which can be given to a spur is that in which it forms with the down-stream bank an angle of 45°.

The following descriptions will illustrate the successful application of this theory, and the use of such simple appliances as the so-called 'Brownlow weeds' to the training of the Indus floods at Shah Jamál.

The Government have for a number of years past, devised various means to keep back the floods of the Indus from inundating the surrounding districts, by throwing up massive bunds and embankments, some distance back from the sides of the river. These have answered their purpose fairly enough until the Indus approached them, when the erosion setting in made short work of the most massive of earthworks, and swept out everything else which opposed its onward and erratic course. At Shah Jamál, lines and lines of these bunds have been run up, one behind another, for many years past, only to be carried away by the succeeding flood's season, (*vide Plates* XI., XIII. and XIV.) At one point, in particular, may be observed the multiplicity of bunds, thrown up to check the Indus from pursuing a westerly direction and towards the head of the Dhundi canal. The end of the great embankment of 1864 was over four miles east of the present Dhundi head. In 1870, an addition became necessary, owing to the erosion eating away half a mile in that direction, at the end. This was followed by a further addition of embankment, directly behind it in 1871; and running in a direct line from near the Shah Jamál choki, to a point on the 1870 bund. The 1872 bund was run up a mile behind that of 1871, and almost parallel to it, until it joined the

Dhundi canal head,—which was then three miles from its present mouth. A Loop-line followed this in 1874, which was eaten through last year. Some are inclined to think that the Dhundi canal had much to say to the Indus pursuing this westerly direction, it having dragged the stream over towards its head and encouraged the terrific encroachment along this reach; but I am not in favor of this opinion, and shall give my reasons further on, merely stating now that the Dhundi canal is with full supply about one four hundred thousandth of the discharge of the Indus at this point; so practically it can be of little moment in dealing with the flood supply. The Dhundi being an inundation canal, it is dry during the winter months, when the difference would be still more marked and the theory yet more untenable.

The massive embankment of 1875, thrown across the strip of land between the Nur and Dhundi canals, was placed three miles from the rivers edge. It was constructed like the others, with a view to hold back the floods of the Indus from inundating that portion of the district, to protect villa-



ges, lands, and a great amount of property, and for the maintenance of irrigation operations. With the Nur and Dhundi flank bunds, this embankment contained nearly eleven millions of cubic feet of earthwork, and was completed by me in less than two months' time, and in the usual local manner, peculiar to this part of India, viz., by the *scoop* drawn by a pair of bullocks. To load this, the driver stands on the front edge, the bullocks are driven on, when the tray buries itself in the earth, the man then steps off, and the *scoop tray*, containing the load is dragged up the embankment, a string fastened to the tray from behind is pulled, when the load is tilted up. In this way all earthwork is done on the frontier. But important as this bund was considered at the time of its construction, and far back as it was placed from the action of the river, it soon became apparent that it also was doomed to go, and it was merely a matter of time how long it would last; for the Indus having taken a dead set in this direction, it worked out a tremendous gap, facing the south end of the bund, and the erosion continued most steadily during the remainder of the season. Four months from the time of completion of the bund, upwards of two miles of rich land were eaten away by the severe action of the main stream, which was within a few hundred feet of the said 1875 embankment; when steps were taken to check the erosion along a very remarkably sharp bend the river took, facing the south-east side of the Big Bund. The annexed table will give the erosion measurements at one or two important points, along this reach, during this period. I have stated that this cutting away of the west bank of the main stream had been steadily going on since the 1864 bund was thrown out to check the terrible inroads of the river, in the direction of the Dhundi canal; that the bunds which had been erected since then, were one after the other swept away, as the river reached them; and the country was time after time submerged by the floods. This demanded the serious attention of the authorities for saving the district. The salubrity of the air which would be restored by properly draining the country and keeping the Indus within its restricted channels, is certainly not the least important point to be considered by the Government. The advisability of meeting the danger, at the very base of operations, was a matter that was carefully considered by the Canal Officers; and I drew up a project about the middle of last year for a breakwater, which should run out and meet the main stream, along the low waste sandy bed of the river, by means of an embankment well protected at the extreme end by concrete blocks along the foot of slope; faced by dry stone pitching on all exposed slopes; the whole held by strong 25 feet piles to keep the blocks together; these piles to be fastened to each other by strong wire interlaced from top to bottom, in case undermining or unequal settlement should take place, or any part of the base give way. This project, however, was slightly altered, and after trying many experiments with various kinds of floating breakwaters, spurs, and barrier works, to check the velocity, and thereby cause silt to deposit,—orders were given to defend the sharp bend, already alluded to, from further erosion, by means of 'Brownlow weeds,' thrown out to meet the main current and to act as spurs. These performed their work exceedingly well, and additions were subsequently made to them, so that in time the stream was forced away from the west bank, into near mid-channel, although this part of the river had by this time formed a semi-circular bend with a radius of about a mile. It will be observed by the survey taken on the 21st April, (*Plate* XI.,) that before the stream swept round this sharp curve, it underwent very extraordinary action, forming in its course almost a double **S**; in fact, for some

distance above this point, the violence and changes of the Indus have never been known to occur within such a short time. It will be advisable, for convenience sake, to number and letter these sections of the river as follows:—Reach above junction with Larkiwalla creek, A1. Below Larkiwalla creek to V's creek, B2. From V's creek to Tiger Island, C3. From mouth of V's creek down channel to opposite bund of 1872, and Loop-line, D4. The sharp bend from this point round by head of Dhundi Canal, E5.

After the floods were over last year, a narrow, shallow creek, was discovered, which was newly formed, and which connected the horse-shoe shape of the river from a point near the Sheru and Muzuffergurh ghâts to the old Lundi ghât. This creek is known as V's creek, and measured about six miles in a direct line.

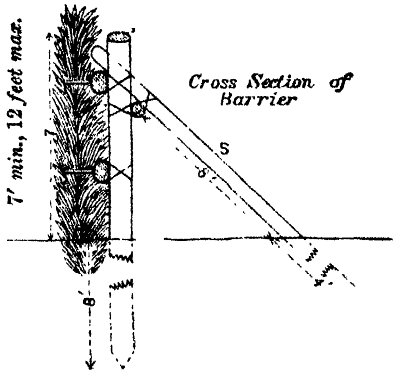
The idea occurred to me to divert the main river of the Indus down this channel, and—by means of certain works (which I shall hereafter describe) placed across the river at the head of this creek when at its minimum supply—to dam the stream, so as to force more water down the channel. It would from the nature of the right bank eat its own way through, and as the draw would necessarily be so much greater direct than all round, the main stream, with a little encouragement, would eventually on the river rising take the shorter and more natural course. Both Mr. Garbett and Mr. Ivens supported my views in this matter, and allowed me to carry out my project, and with their professional advice, I accomplished the whole undertaking, and forced the stream away on to the other side, in a very satisfactory manner.

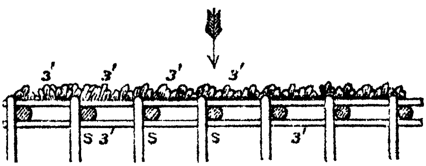
I shall now proceed to describe the method of carrying out the diversion and defence works. The creek ran dry early in December, but by clearing out the accumulated silt at the head, the channel was re-opened, and 300 cubic feet per second passed down: by cutting the sharp neck through, the volume of water was increased to 1,000 cubic feet per second. The creek was further straightened, and a strong 500 feet catch-barrier thrown out, across the main stream *below* the mouth, which caught more water and forced it down the channel. By means of hand dredging at the bar-head, 500 coolies increased the volume in two days to 2,200 cubic feet per second, although the river did not rise a fraction. From the peculiar formation of creeks of this sort, taking off abruptly from the main stream, there is always a tendency to silt across the bar-head, and at the tail, and it is only by clearing this constantly away that such channels can be kept open. The nature of the stuff through which this creek passed was stiff clay on the east or left side. The banks were high for this part of the Indus, and thick impenetrable tree and other jungle lined the east shore. The bottom, entire bed, and right side of the channel were of an alluvium deposit—soft and quick, and low friable sand banks covered the space between the waters. At only one place, known as Tiffin Point, were the banks of any elevation, and this point jutted prominently out and met the main stream.

It was here that I succeeded in placing auxiliary barriers in such a position, that with the action of the main current they were directed to catch, scour, and help the river in its work of eroding and cutting out a greater mouth at the head. The bank being friable sand, the work was accomplished with comparatively little labor. A small channel was subsequently cut across the narrow neck facing Tiger Island, and a freshet coming down about this time, a vast quantity of water was forced to take this course, the consequence was from a small channel 10 feet wide, it became in a single week 80 feet at the bed, with a tremendous draw down it and a velocity of six feet per second—the sandy sides fell in, and before the end of March, all the smaller streams joined here and became one channel, with a minimum width of 400 feet, (now 3,500 feet): the discharge at the end of March was calculated at something over 7,000 cubic feet per second, or about one-fifth of the whole volume of the Indus at that particular time of the year.

The tendency of the river at A1 was evidently to pursue a straighter course in the direction of the Loop-line, and the erosion was actively at work when measures were taken to stop it. The sand banks on the right of the stream were very low, and being only about 2 feet above the water line, were easily eaten away by the current, which set in along this reach. Very remarkable changes took place here during March. The main stream was continually changing its course, and on the 12th it cut out 800 feet in 24 hours, and passed through 200 feet of the advance flank. The main defence line of barriers was undermined, and fell over into the river. The current for some days was working into the soft sand, and doing very serious injury to our defence works; when I constructed an auxiliary flank higher up at the junction of the Larkiwalla creek tail and main stream. The piles were worked

8 feet into the sand, and stood out 12 feet above the bank, the whole were strongly interlaced in the usual manner with *lei* brushwood (*see* figures) cross bars, supports, and counter-supports were added to the line, which extended 900 feet from the head, and so placed as to throw off the stream, on the river rising over this low bank in this direction. To help this barrier work, a floating breakwater of stacks of jungle, *vide Plate* XII., were thrown out from the end of this point into the stream, and measured 500 feet in length; others of greater size were added lower down, and when the velocity was diminished, the main line barrier was repaired and considerably strengthened. This main line measured over 8,000 feet. The spurs, shoots, auxiliary barriers, and flanks, placed in such a manner as to turn the river away from this point, aggregated 2,000 feet. Three different times were the works swept away at the end, simply by undermining, but the massive floating breakwaters from above, decreased the velocity along this reach, thereby collecting enough silt to work on, and so I advanced bit by bit with the strongest barriers into the current, and obtained in time a good position. The floating breakwaters were always so placed as to help the general working along this dangerous shore. I cannot speak too highly of these simple contrivances of floating breakwaters composed entirely of stacks of fascines and jungle. The results obtained were truly marvellous, and achieved even greater things than those tried at the end of the 1872 bund during last season.



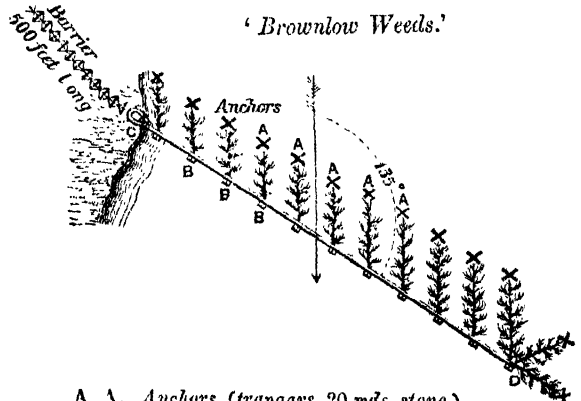


Plan

Some of these breakwaters were 4,000 feet long. The main cable measured one foot in circumference. Attached to the main cable were supports from the shore at every hundred feet or so—if the shore was not safe, they were held by anchors at suitable distances, (*vide Plate* XII.) The stacks of jungle were about 20 feet long and 10 feet in diameter, they were held by four-inch rope. If that was not strong enough it was doubled. The stacks were thrown over at every 20 or 30 feet. In some places a dozen stacks have been thrown over in one place. They should not be used sparingly, and they do no good until the velocity of the stream is decreased to two feet per second, when silt accumulates and the result is obtained.

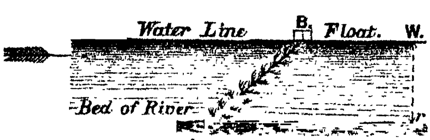
Brownlow's weeds (which are fascines held by an anchor (A), and sup-

'Brownlow Weeds.'

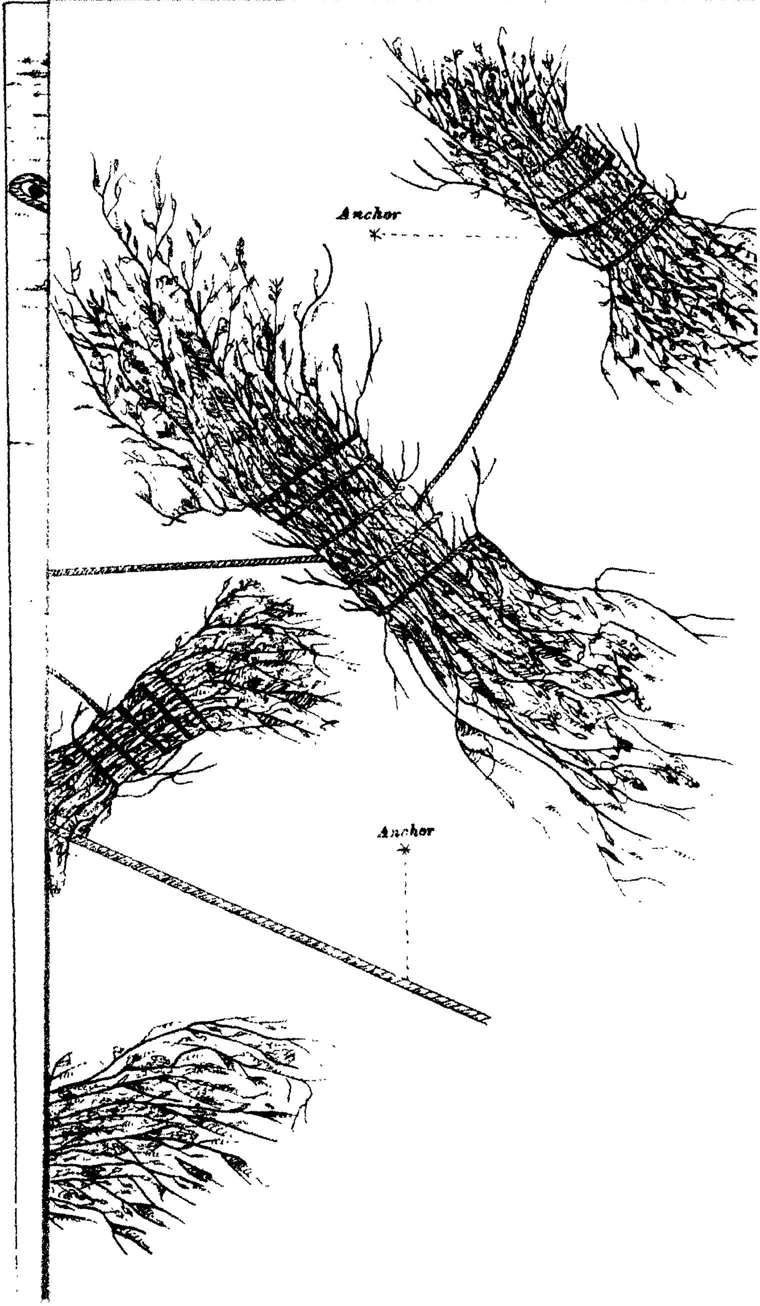


A, A. *Anchors, (trangars, 20 mds. stone.)*
B B. *Floats, (empty casks.)*
C, D. *8" main cable, (múnj rope.)*

ported by a barrel (B) which floats) should never exceed twice the depth of the water. If longer, the rope with the fascines will sink, and forms a parabolic curve, when it only does half its work. It does not matter if the cask sinks a foot or so below the surface, the work of silting is going on more rapidly from the bottom. It is a mistake to suppose these weeds are any good when 20 and 30 feet apart. They are utterly useless unless *together in a clump.* Sometimes to check the velocity, I have had three and four directly behind each other: it should be borne in mind that 'unity is strength.' The revolving casks are expensive. The weed should be so constructed that the cask should be just submerged, it will then work perfectly.



Depth W *r being* 1, *length of "weed"* (A *to* B) *to be* 2, *distance apart* (B *to* B) 5 *feet.* C *to be well defended.*


Anchor
Anchor

The main current crossed over from opposite Larkiwalla creek and turned sharp round from the barriers and breakwaters just noticed, back in the directions of V's creek, forming in a short distance of 5,000 feet a complete **S** curve, and rebounding from shore to shore, one current running parallel to the other in just the opposite direction on its return. The draw down V's channel became very great, and I seized the opportunity of placing 100 of Brownlow's weeds close up under the current, and across the main stream on the right side of the river—double lines of weeds were adjusted, and strong barriers thrown out to check and retard the river from passing down its old course. The main stream had actually eaten into the head of the channel, but rebounded sharp back. The erosion became very great to the left of this point, and 2,500 feet of the soft low sand banks were eaten out in a single day. This very much helped the work of scouring out and enlarging, and the channel, which afforded the only means of escape for the backed up water, became each day larger as the sides were eroded and fell in. Tiffin Point went, and the temporary barriers were instantly removed. The line of Brownlow's weeds had now to be altered to some point lower down—the ropes were cut, casks removed, and the old weeds sunk. The second plan which was surveyed on the 27th May, (*vide Plate* XIII.,) will show that the thread of the stream became more direct, and from the sharp and unnatural bends in the river from reach A1 above Larkiwalla creek, the whole current swung round, quite half passing down V's channel, the remaining following its old course. It was not until the new line of weeds had been readjusted and placed about 45° with the original channel, that the Indus was finally checked, and the entire river left its old course. In May, this became an established fact; for the Indus once turned off, the old bed began rapidly to silt up. The following is a list (page 100) of the depths and soundings taken from end of the 1872 bund, and in a direct line with it across to the other side. Its gradual silting up in so short a time is worthy of remark.

The contortions of the river in reaches D4 and E5 early in April, bounding and rebounding from one side to the other in sharp curves, resulted in eroding a very large bay below the Loop-line bund. The action of the current was very severe here, and a series of eddies and whirlpools did great damage to the west bank. A considerable number of Brownlow's weeds were thrown out (as shown in *Plate* XI.) which

Soundings across Indus from end of 1872 bund to left or east bank. Deduced to one level for comparison. Observed by G. W. Vyse.

Distance in feet.	Soundings taken on				Remarks.
	1st May.	15th May.	30th May.	15th June.	
0					
100	18	12	5	0	
200	15	9	3	3	Brought down to one level; full feet taken, the nearest decimals to the foot shown.
300	11	9	3	1	
400	6	6	3	1	
500	4	3	...	...	
600	4	4	...	...	
700	3	3	...	...	At 200 there was running water brought down from Nur creek.
800	2	2	...	...	
900	5	4	...	...	
1,000	5	5	...	...	
100	8	7	...	...	
200	9	7	...	...	
300	10	9	...	...	
400	10	9	...	...	
500	10	9	...	...	
600	11	9	...	...	
700	9	9	...	...	All this mud and slush deposit many feet deep. Each flood and freshet added to the height. The only water which passes over this is surplus overflow from creeks and channels west.
800	8	7	...	...	
900	8	7	...	...	
2,000	7	5	...	...	
100	8	6	...	...	
200	8	6	...	...	
300	6	5	...	...	
400	6	5	...	...	
500	6	4	...	...	
600	6	4	...	...	
700	6	5	...	...	
800	6	5	...	...	
900	6	5	...	...	
3,000	6	5	...	...	
100	6	6	...	...	
200	7	6	...	...	
300	7	7	...	...	
400	7	7	1	1	
500	8	8	2	2	
600	8	8	3	2	
700	8	7	4	2	
800	8	8	3	2	Surplus overflow, from creeks and channel. This water supplies the Dhundi canal.
900	9	8	3	2	
4,000	10	10	3	2	
100	11	10	3	2	
200	11	10	3	2	
300	12	12	3	1	
400	13	12	4	1	
500	14	13	4	1	
600	14	15	4	1	
700	16	15	4	1	
800	17	15	4	...	
900	16	14	4	...	
5,000	17	15	3	...	
100	18	11	3	...	
200	13	8	3	...	
300	10	1	2	...	
400	4	0	0	...	
440	0	0	0	...	

Banks
M
Low Sand B
LARKIWALLA
D
No. 4 EL
No. 5 EL
DHUNDI
K
CAN
REFERENC

checked the direct action of the stream. The current of the river formed a perfect backward **S** in this particular reach. Lower down a whirlpool of terrific force played about, and tore out the sides and scoured the bed. It would be impossible to state the number of weeds it swallowed, and the floating breakwaters it demolished before its action was destroyed. The maximum depth of water in this bay, was 25 feet on the 20th April; on the 1st May, it was 23 feet; on the 15th May, 12 feet; and on the 22nd May, the river having fallen a little, a silt bank showed itself along the entire length of the bay.

Along E5 reach, the silt by the 30th May had deposited itself round the entire curve of the original channel where a month before the Indus flowed, and so great an amount of slush and silt was accumulated, that it was with difficulty the small rowing boat could be brought round. Large country boats passing up and down the river began to run aground early in May, and by the middle of the month, as they could not possibly succeed in getting round, were compelled to take the diversion course where the stream was so strong.

The following table will show the increase and decrease of velocities per second at some of the most important points in the old-round-about channel the river was leaving, for the new course (B2, C3), where the draw and gradient were so much greater than by E5.

No.	Velocities per second.					Facing erosion lines Nos.	Remarks.
1	9ft.	12ft.	9ft.	10ft.	12ft.	...	Opposite Tiger Island, West bank, C3.
2	7·0	8·0	9·0	9·0	10·0	No. 7	On East bank.
3	5·0	6·0	5·0	4·0	4·0	No. 0	On West bank.
4	2·0	1·5	1·5	1·0	...	No. 1	Edge of 1872 bund.
5	1·5	1·5	1·0	...	1·0	No. 3	West bank.
6	2·0	2·0	1·0	1·0	1·0	No. 4	Do.
7	2·5	1·5	1·0	1·0	1·0	No. 5	Head Dhundi Canal.
Direction of wind,	S	S	N	S	S	Calm.	The floats were bottles.
Observed date & month.	18th May.	28th May.	4th June.	11th June.	17th June.	Eddies, &c., avoided.	The average of 5 floats taken.

(Observed by G. W. Vyse).

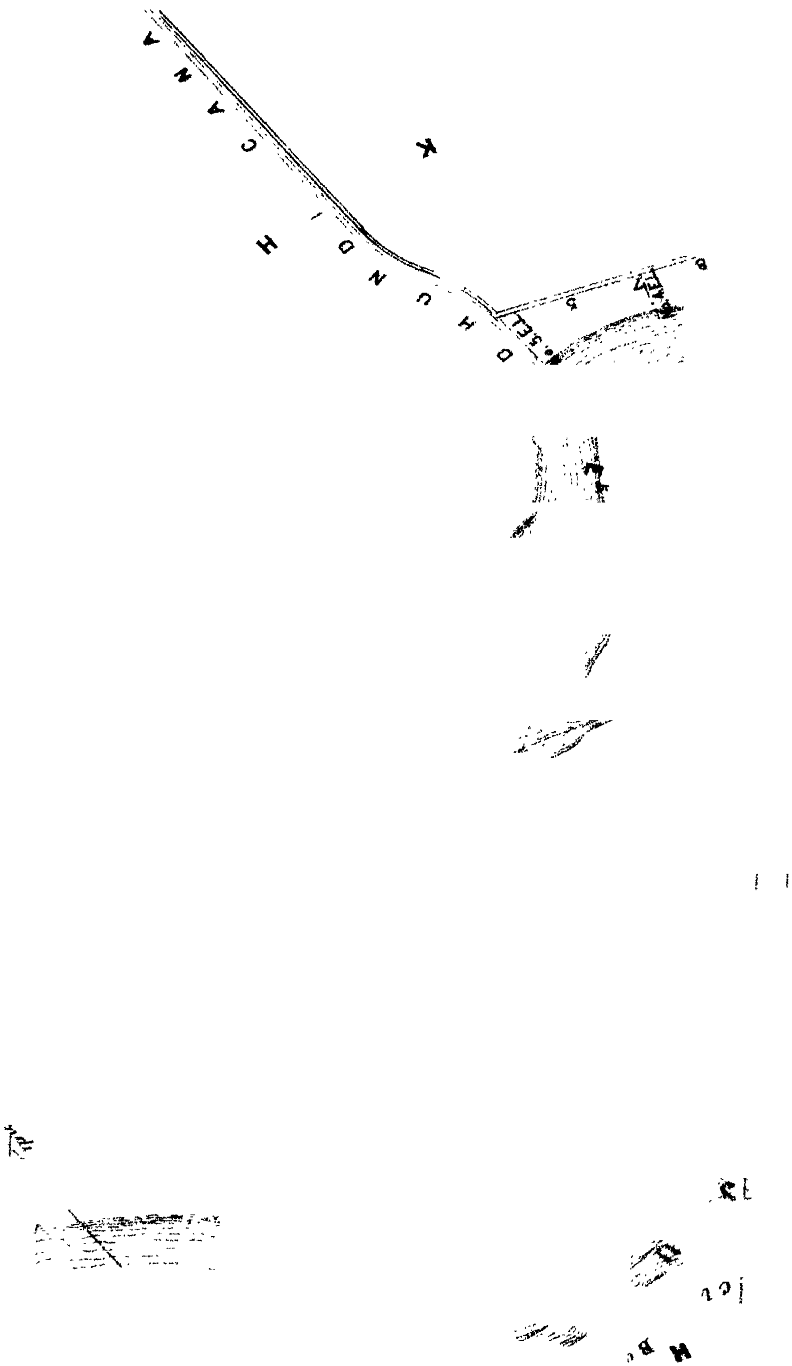
N.B.—Where the velocity is above 3·7 feet per second, silt will not deposit: velocity here, means Surface Velocity.

The surveys of the river, I made at the most eventful times, and when the changes will show most, viz., on the 21st April, 27th May and 17th June, (*Plates* XI., XIII. and XIV.) The lines of works showing general arrangement, the various currents of the main stream, erosion lines, and diversion enlargements, bunds, defence and protective works, barriers, weeds and flanks, are all shown. The sheet of water between the 1864 bund and the V creek, and again in the old channel opposite the Dhundi canal, will be an enormous area when the river is in flood, but its velocity is rapidly decreasing thereby, showing that silt is fast accumulating and depositing very evenly—it can only be a matter of time when the whole will silt up and become reclaimed land again. The barriers and floating breakwaters are considerably strengthened since the floods, as the *dèbris* is a vast field above and below the defence and flank works, which if properly guarded at the head, nothing can destroy or sweep out. If the scour increases in the reaches B2, C3, it may be found necessary to throw off the current by means of a new line of weeds, but at such a time the utmost caution should be exercised in using weed spurs.

The protective works are secure beyond a doubt for the remainder of the season, but at the same time they should be carefully guarded and watched.

The river has now been forced over on to the extreme east bank, and it is possible this change may influence its course and action for a considerable distance about the Sheru and Muzuffergurh ghât reach. I am inclined to think it may seriously effect the scouring out of the Larkiwalla creek in the course of time, and from observations and notes taken, the tendency certainly appears for it to do so.

I think I have shown the use of these floating breakwaters, barriers and weeds, and how they can be worked in protecting the encroachment of the Indus, and how they can be placed when the river is in a low state, to change and divert its course back to its old channel, or check the severe erosions which are continually going on. The whole theory being that one ought to *turn off the current at the very edge of the erosion*, and that the spurs and weeds fixed lower down should be so placed, and at *such proportional distances*, that they might *mutually support and be supported by each other*, care being taken that the flanks are secure, otherwise in all schemes of this description of defence, unless the impossibility of a breach is demonstrated, the remedy proposed is worse than the existing evil.



I have said nothing about the various estimates drawn up at different times for the protective and defence works of the river at Shah Jamál, because I think they would prove of little interest or value to any one not working in this particular locality. I had been very fortunate at first in having ample brushwood and stakes growing within the immediate vicinity of the works, and on lands of the villagers, who were only too glad to have the same removed, in order to clear their grounds for crops. The cost has therefore been comparatively small as compared with other places, as I utilized all the material at hand before I touched the Government rakhs. On the east or left bank of the Indus stands a vast impenetrable jungle, belonging to the Forest Department. This rakh was very handy for the work on that side, and I was greatly indebted to the co-operation and assistance of the Forest Officer. I had the good fortune to have good brushwood, wattle and timber for all purposes growing along this shore, for the diversion works.

The stone for anchors were boulders of great size and weight, brought by camels from the neighbouring Belooch hills about 60 miles off. The Deputy Commissioner and Lagari Chiefs helped me in getting 1,000 camels, and it was through their exertions, I was able to perfom this part of my task.

The large cable múnj ropes were manufactured at Muzuffergurh and at the jails of Dera Gházi Khan and Dera Ismail Khan. The smaller ropes were made on the spot, or bought at the neighbouring towns.

I did as much of the barrier work as I could by contract, at from Rs. 10 to Rs. 14 per 100 running feet. Staking, piling, bracing, &c., were also given out by contract, from six pie to an anna and a half per stake. The higher rate was given if they worked in water. I estimated "Brownlow weeds" at Rs. 13 each complete, but I found they did not cost Rs. 8 on an average. Sloping the sides of the embankment where excessive erosion was at work, cost Rs. 1-4 per 1,000 cubic feet. Coolies employed in opening out the head of the creek, and removing the bars of silt across the mouths and otherwise engaged in "hand dredging," received 2 annas and 3 annas per day. Occasionally I got the Beloochees to take these jobs by task work, and then it was executed at a very trifling cost, and in a remarkably short time. When breaches occurred in any flanks, the best plan was to muster sufficient men in a body and make them stand together, *packed in a mass*. A spare 100 or so with brushwood and fascines ready at hand to "pack the breach" would often close an almost impossible gap of rushing water, and in a comparatively short space of time.

When the force of the water is so strong that a man cannot stand against it, knots of men in twos and three together catching hold of each other, can pass a rope from one side to the other of the gap—as the men are powerful swimmers there is no danger. Some of these men will prefer to swim the Indus in flood (going over a distance of 12 miles) rather than pay the two pice ferry toll.

The best and strongest múnj foot rope for main cable, costs at site of work, Rs. 5 per 100 running feet. Eight inch múnj rope, same pattern, Rs. 3 per 100 running feet. [*N.B.*—Any múnj rope when once submerged should remain under water, else the sun will rot it very soon. Those ropes that are exposed at the junction of the water and bank should be well oiled which will repel the water.]

The trangars for anchors should be sound múnj rope, and each part of the net well tested before being launched. The sketches and drawings of the barrier work, &c., will show the method of interlacing and bracing the brushwood, and its cost varies from Rs. 10 to 15 per 1,000 lineal feet.

The cost of a single floating breakwater 1,000 feet long, composed entirely of jungle, including weighting the same, auxiliary ropes and supports, complete, should never in any part of the Punjab exceed the following estimate:—

		RS.	A.	P.
1 main cable, 1,000 feet long, ...		50	0	0
10 auxiliary ropes, 100 feet each, ...		30	0	0
40 support, or branch ropes, 50 feet, each 8 as., ...		20	0	0
20 anchors, each trangar, ..	Rs. 1 0 0			
20 maunds stone, ..	" 3 0 0			
20 ropes to cable, ..	" 2 0 0			
Splicing, ..	" 0 4 0			
Loading and launching,	" 0 4 0			
	Rs. 5 8 0 × 20 = ..	110	0	0
20 stakes, 20 feet long,..		20	0	0
20 " driving and arranging, .. .		2	8	0
100 stacks of brushwood, including royalty, cutting carrying, packing, 20 × 10 feet, at Re. 1 each, .. .		100	0	0
10 lbs. string,..		2	8	0
34 maunds stone for loading stacks, .. .		50	0	0
Mate or Chaprassi,		8	0	0
Contingencies,		12	0	0
Cost of each 1,000 feet floating breakwater—Total, ..		400	0	0

The works I have been alluding to came well under the following sub-heads:—

	RS.	A.	P.
Breakwaters, aggregating 20,000 feet lineal feet, in length, ..	4,700	0	0
Barriers, aggregating 13,000 feet, lineal feet, ...	1,560	0	0
Royalty, ...	400	0	0
4,600,000 cubic feet earthwork and hand dredging, at Re. 1 all round, ...	4,600	0	0
Additional fascine work, ...	780	0	0
Weeds, spurs, &c., &c., ...	3,000	0	0
Total, ..	15,040	0	0

But I quite agree with Major Thorold, R.E., when he says in speaking of such estimates—"Working against such a great and varying force as the River Indus, and with banks of such a fragile material as loose sand, it is impossible to estimate *exactly* what the cost will be." The locality, time of the year, and the labor market, greatly influence the expenditure on such works.

The result of the 1875-76 work at Shah Jamál has been diverting the River Indus, sending it well over to the other side of our works, saving our canals, inundation bunds and headworks,—saving two miles of encroachment, and reclaiming over six square miles of rich arable land,—such has been the result, which has saved Government over five lakhs of rupees.

With Mr. Rayne's permission, I inspected the training works of the River Sutlej at Adamwahan, in company with Mr. Medley, the Engineer directly in charge of the same, who most kindly showed me everything worth seeing, and the able reports drawn up by Colonel Peile, and other Engineers. These works have been on a very extensive scale, and cost about Rs. 4,00,000 in three years. Colonel Peile appears to be in favor of barriers of stonework; the necessity, however, for these is questionable in a river like the Sutlej, whose waters are charged with such a vast amount of silt and débris as to make it the most invaluable agency if properly turned to account. It appears also to me that too much is demanded of one, or at the most two advanced spurs, to check the direct action of the main current. Where spurs or weeds have no supports, above or below them, and where due regard is not paid to the direction of the flood current, they are liable to become isolated, and, on the river rising, to be broken and detached; if breaches once occur at the haunches, and proper precautions have not been taken at the flanks, the whole runs much risk of soon becoming a wreck.

At any rate, I think it will be admitted, that the past season's experience on the Indus at Shah Jamál, shows how much can be effected by the far less costly agency of fixed barriers, floating breakwaters, and 'weeds,' constructed of rough woodwork and gabions, fascines, or mere bundles of brushwood: and that the cost of these successful protective works, as above described, will compare favorably with that of works executed elsewhere with a similar object.

G. W. V.

No. CCXX.

MONOLITHIC FLAT ROOFS OF CONCRETE.

[*Vide* Plates XV. and XVI.]

Report by P. DEJOUX, ESQ., C.E., *Exec. Engineer, Cement Experiments Division.*

Dated the 26th August, 1876.

THE following report deals with the working capabilities of lime and cement concretes for use in floors and flat roofs without any support other than the walls of buildings.

Flat roofs of concrete for spans of 15 feet have been very successfully laid in France by Mr. Coignet; the concrete used was either pure artificial stone, or a mixture of materials used in the fabrication of artificial stone and broken pieces of stone or gravel. As I was one of the Engineers of Mr. Coignet, and chiefly in charge of the then new experiments tried from 1863 to 1865, many such roofings were constructed under my direct supervision.

The following is an extract from Mr. Coignet's pamphlet, published in 1865, relating to the subject:—

"*Terraced Roofs.*"

"With regard to terraced roofs, the monolithism and resistance of agglomerated béton (artificial stone) will give entirely new results and resistance until now unknown in architecture.

"If small spaces of 12 or 15 feet have to be covered in, it will be sufficient to lay on the walls a layer of artificial stone of sufficient thickness, say from 10 to 12 inches, which will form a roof and terrace of great stability. Should large spaces have to be dealt with in the same way, a system of some double girders must be used, crossed by joists at a distance of three feet from one another. These light girders are fitted in the artificial stone like in a tight case of hard stone, and being confined at all parts of their surface will not deflect, but act rather as tension bars. Spaces of 70 × 22 feet have been covered in this manner. A flooring of this kind on the top of a house, forms a perfectly impermeable terrace, resisting the inclemencies of frost and heat.

"We have therefore, for the first time, attained the possibility of making in our damp and variable climate, roofs and terraces perfectly water-tight.

"FRANCOIS COIGNET."

Mr. Coignet was always of opinion, and practical experience subsequently quite proved, that such flat roofs on obtaining sufficient hardness act as flat slabs, resting on the walls without exerting any outward thrust on them.

The same remarks may be applied to the arches made in artificial stone with a low rise varying from one-fifteenth to one-tenth. I made some of 20 and 25 feet span, resting like a beam on two solid walls without any buttresses.

The following is a certificate for 3,280 square yards of vaults which were used as stable floors of the barracks for the Municipal Horse-guards in Paris.

"CITY PARIS.

"*Architectural works of the 5th Arrondissement,*

Paris, 8th August, 1865.

"The Chief Architect of the barracks and Staff quarters of the city, certifies that Messrs. Coignet and Company, Constructors in agglomerated beton (artificial stone), have, under his direction, executed the following work for the City of Paris :—

"Low roofed arches with a rise of one-tenth and 17 feet 6 inches span (*vide Plate* XV.) at the city barracks ; these have undergone numerous experiments to try their resistance, and we have had every reason to be pleased with the use of Coignet's Béton, in the celerity of execution, as well as for the appearance and solidity of the work.

"This work has fully proved that 'Coignet's Béton' could be usefully employed in public works, and decided us to order *monolithic flat roofs,* which will bear the same loads and undergo the same wear as ordinary ones.

"V. CALLIATT,
"*Chief Architect.*"

P.S.—"At Mr. Coignet's request, I specify the following experiments made to prove the resistance of the vaults :—

"*1st,*—A cube weighing 29 tons placed as a pyramid in the middle of a vault 17 feet 6 inches span, (*vide Plate* XV.)

"*2nd,*—108 cubic feet of sand (4¼ tons) on a base of 10 square feet.

"*3rd,*—And lastly, the passage of loaded waggons and the unloading on these vaults of stones destined for the building of the walls. All of which did not cause the least crack or fracture.

"V. CALLIATT."

PLATE

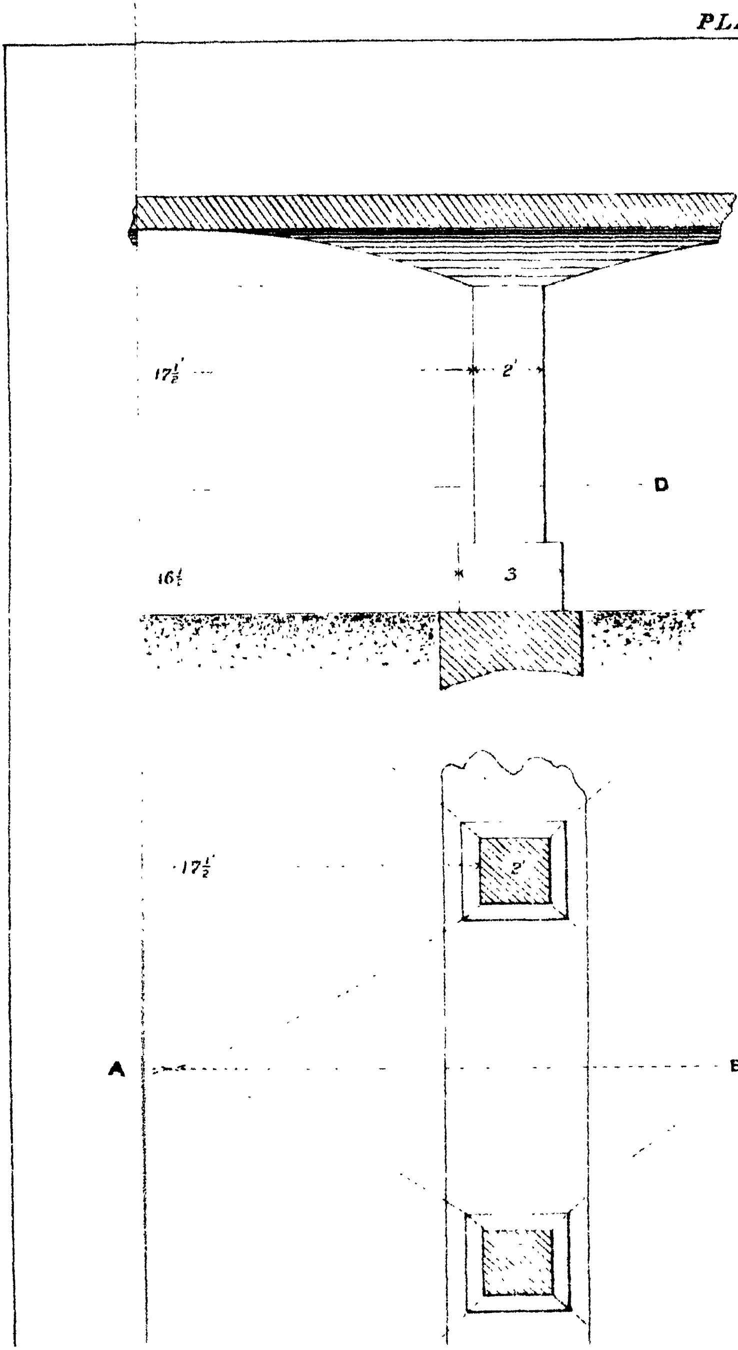
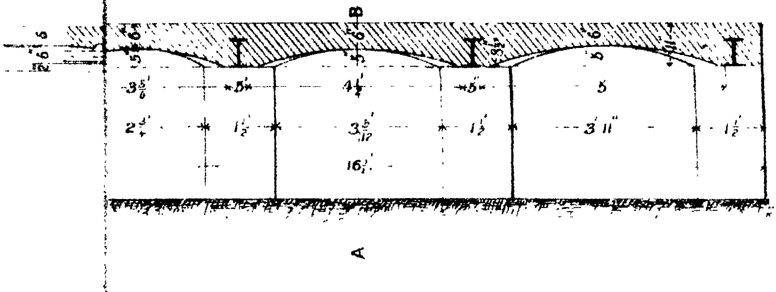
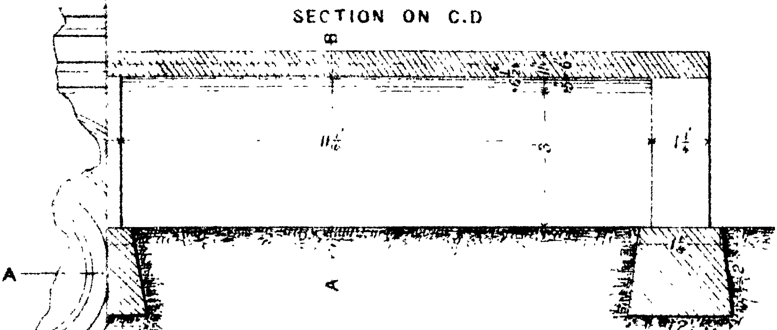


FIG. 2.

SECTION ON A.B

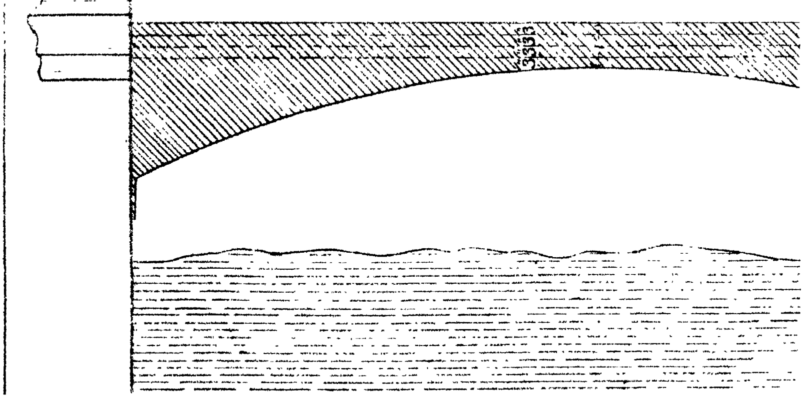


SECTION ON C.D



Scale—¼ of 1 inch = 1 foot.

FIG. 3



This work was made under my personal supervision, and before leaving France, I had time to superintend the building of a dozen *monolithic flat roofs* (mentioned in the certificate of Monsr. Calliatt), which proved a perfect success.

These were hollowed in the centre, and as well as I recollect, their span was 15 or 16 feet, with ornamental moulding, (*vide Plate* XVI., *Fig.* 1.) The question was for a long time discussed so as to decide whether flat roofs of this kind were better when made with the same thickness right through, or when they were hollowed in the centre. Opinions were divided; however, I agreed with those who were in favor of the latter system, besides it caused a considerable saving in the quantity of material used.

For flat arches of a large span we used to put, as shown by *Plate* XVI., *Fig* 3, about three layers per foot in thickness of small pieces of either square or round iron wire one-twelfth to one-eight in diameter, not exceeding two feet in length.

These pieces of iron were found quite sufficient to prevent any accident in case of slight cracks on the roof, arising either from accidental causes or bad workmanship; and in fact if such an arch cracked (even throughout), it would bear considerable weight before giving way.

It may be added that iron is free from rust when buried in artificial stone, and I can show specimens made 10 years ago which have been under water a long time, and which when broken show the iron in its original state.

Some experiments were also made by me in India in both small and large vaults in artificial stone on Coignet's system, when I was Chief Engineer of the Patent Stone Company. and one particularly was made at the request of Government; but owing to my absence then from Calcutta, the experiment was conducted by Mr. Downes, according to instructions left by me, and the result of it will be seen from the certificate below:—

"*Experiments with artificial stone, Coignet's system, in vaulted floors.*

"With the view of testing the applicability of this artificial stone in the construction of vaulted floors proposed to be used in flooring of the upper stories of the new Warehouses in the Naval Store-keeper's Department, Government Dock-yard, Kidderpore, and the advisability of its general introduction in public works, the association were invited to construct a series of vaulted floors on wrought-iron girders.

"The girders used were 8½ inches in depth, with a clear space of 11 feet 2 inches, the vault was six inches thick at the crown, with a rise of 5 inches, and the vault tested was 4¼ feet span, (*vide Plate* XVI., *Fig.* 2); the whole series being constructed of a single block of artificial stone, presenting a uniform level surface at top for the floor of the upper story.

"A load of 22·78 tons was placed over the vault, covering a surface of 44·61 square feet, giving a distributed load of 0·41 tons on the square foot.

"Although the vaulted flooring which was constructed on the 9th June, had remained exposed to the alternating influence of sun and rain for nearly a period of three months, it was entirely free from fissure, and was perfectly water-tight.

"The load was applied on the 21st August, and the experimental vaults were inspected on the 28th by Captain W. R. Tucker, R.E., Executive Engineer, Presidency Division, and Mr. Vernon, Assistant Engineer, and on their report we, the undersigned, certify that the experiment which was conducted throughout by Mr. Downes, Engineer to the Association, was satisfactory in every respect.

"W. S. TREVOR, MAJOR, R.E.,
"*Supdg. Engineer, Presidency Circle.*

"W. R. TUCKER, CAPTAIN, R.E.,
"*Exec. Engineer, Presidency Division.*"

NOTE.

I may state that the contract for the vaults of the new warehouses was not given to the Patent Stone Company, on account of the estimate being found a little too high. This could have been easily avoided by putting the girders 12 feet apart instead of 4 feet 6 inches. I feel certain that it would have been quite as strong, and thus the total cost of the roof would have been somewhat less by using artificial stone instead of brick arches of 4 feet 6 inches span.

If such floors or vaults are to be made in India, I would strongly suggest the use of either artificial stone on Coignet's system, or what I may call a mixture of artificial stone and concrete, which will be almost as good and costless.

In the first case, when good hydraulic lime is obtained, I recommend a mixture of—

4 to 5 parts of sand,
$1\frac{1}{2}$,, hydraulic lime and
$\frac{1}{2}$,, Portland cement.

But if the cement is not quite fresh, three-fourth parts should be used instead of half.

The lime must be very fine, free from all impurities, and should be passed through a sieve of at least 20 meshes to the lineal inch.

Fat lime always gives poor results, so does súrkí; coarse and sharp sand is the best, and must therefore be used instead of súrkí.

If a mixture of artificial stone and concrete is used, it should be done in the following manner:—

Put first a layer of the (artificial stone) mixture, ram it well, scratch the surface, pour broken pieces of stones over it, so as not to stick together (these stones must be first soaked in water, in which it will be as well to add some cement), and lastly spread over (so as to cover entirely) some mixture of artificial stone and ram it well. This process is to be carried on alternately, the top layer being laid with only artificial stone.

The proportion should be from one or one-half parts of broken stone, to one of artificial stone mixture.

The preparation of this mixture is made in a special pug-mill, and I consider it unadvisable to use any other process.

Such mill may be worked either by hand, by bullock, or by steam.

I feel quite sure that roofs of the descriptions above noticed, will be reckoned of great importance in India, particularly as vast savings would accrue from dispensing with supporting beams of wood and iron in buildings; and indeed I have for the last 10 years been trying to introduce them in the Public Works Department; but it must be urged that such works cannot be brought to satisfactory results, unless they are placed under careful supervision, and constructed with only first class materials.

I annex, for readier reference, a copy of a letter from the Executive Engineer, Cossye Division, reporting on the quality of the artificial stone made under my directions in Hidgellee, 7 or 8 years ago, of which, while portions were in blocks of sizes, others were monolithic, and which have been ever since exposed to the action of salt water.

Dated Midnapore, 30th June, 1876.

"At the time of fixing the portevalets to Tarapakea and Itamugra locks, I failed to bring distinctly to notice the very superior quality of the artificial stone used for coping and quoins in the above locks. In cutting out the recesses for the portevalets, it was necessary in both the locks to cut through the coping and in the Tarapakea lock also through a considerable portion of the quoin stones, so hard was the stone, that it had to be hewed out with pointed cold chisels like granite, and having to do this caused very considerable delay in the execution of the work.

"The brickwork in these locks was also of a very superior quality."

In conclusion, I need add that over three lakhs cubic feet of artificial stone have already been manufactured in India for various works.

P. D.

No. CCXXI.

THE FOLLOWING IS AN ABSTRACT RETURN OF THE RISE AND FALL OF THE RIVER GANGES DURING 1875.

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

		Highest level above zero of Ganges in the week ending				Remarks.
		7th	14th	21st	31st	
January,	Benares, ..	3′ 11½″	3′ 8½″	3′ 5½″	3′ 4″	
	Mirzapur, ..	3′ 10″	4′ 0″	3′ 10″	3′ 5″	
February,	Benares, ..	2′ 11″	2′ 7″	2′ 4″	3′ 3″	
	Mirzapur, ..	3′ 1″	3′ 0″	2′ 11″	3′ 2″	
March,	Benares, ..	3′ 11½″	3′ 11¼″	3′ 7½″	2′ 11″	
	Mirzapur, ..	4′ 2″	4′ 5″	4′ 1″	3′ 4″	
April,	Benares, ..	2′ 0¾″	1′ 6″	1′ 6″	0′ 9″	
	Mirzapur, ..	2′ 5″	1′ 11″	2′ 3″	1′ 10″	
May,	Benares, ..	0′ 10″	0′ 5″	0′ 8″	1′ 6″	
	Mirzapur, ..	1′ 3″	1′ 7″	1′ 8″	2′ 0″	
June,	Benares, ..	0′ 7″	0′ 9″	1′ 1″	11′ 6″	
	Mirzapur, ..	1′ 4″	2′ 0″	2′ 3″	9′ 8″	
July,	Benares, ..	10′ 8″	19′ 0″	28′ 0″	38′ 0″	
	Mirzapur, ..	11′ 2″	20′ 3″	28′ 11″	40′ 6″	
August,	Benares, ..	*44′ 0″	34′ 0″	35′ 6″	34′ 6″	
	Mirzapur, ..	55′ 0″	37′ 7″	35′ 9″	34′ 9″	
September,	Benares, ..	21′ 10″	31′ 6″	33′ 0″	33′ 7″	
	Mirzapur, ..	22′ 3″	32′ 10″	33′ 7″	33′ 9″	
October,	Benares, ..	29′ 7″	19′ 3″	14′ 8″	12′ 6″	
	Mirzapur, ..	29′ 3″	18′ 4″	14′ 3″	11′ 3″	
November,	Benares, ..	10′ 1″	9′ 0″	7′ 11″	7′ 0″	
	Mirzapur, ..	9′ 0″	8′ 0″	6′ 9″	6′ 1″	
December,	Benares, ..	6′ 1″	5′ 6″	5′ 0″	4′ 6″	
	Mirzapur, ..	5′ 1″	4′ 5″	3′ 10″	3′ 6″	

* No measurements taken on 3rd, 4th and 5th August, on account of inundation of the river.

E. D.

No. CCXXII.

A DESIGN FOR THE NEW CANNING COLLEGE, LUCKNOW.

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

By Capt. S. S. Jacob, *Assoc. Inst. C.E., Exec. Engineer, Jeypore State.*

Report.—As desired, this building has been designed to be in general keeping with the architectural features of the Kaiser Bágh buildings.

The total length of front is 412 feet, and the height to top of the dome, not including finial, is 110 feet, and the total depth 278 feet.

The accommodation provided is as follows:—

Examination Hall,	... ...	100′	× 68′
Eight class rooms, each,	... ...	38′	× 28′
European Professor's Room,	... ...	38½′	× 26½′
Principal's,	... ...average	50′	× 22′
Native Professors,	... ...	38½′	× 26½′
Four Bath rooms, each,	... ...	14′	× 12′
Office,	... ...	38′	× 26′
Library,	... ...	68½′	× 30½′
Graduates' Room,	... ...	38′	× 26′
Entrance Hall,	... ...	68′	× 30′
Lobby, under Dome,	... ...	38′	× 38′

A reference to the ground plan of the building is necessary, in order to follow the general description beginning at the top of the plan.

Principal's Room.—Average length 50 feet, width 22 feet, height 24 feet. Beyond the Examination Hall to which it has immediate access. It is easily communicated with from other parts of the building by means of the covered passages or verandahs on each side of the Examination

Hall each 12 feet wide. It is removed from the noise of the class rooms, and is open to the breeze on three sides. In front from its windows can be seen the old tomb of Saadut Khan. Close to it in the verandah on either side are two retiring or record rooms, each 12 feet square, placed so as not to intercept the breeze.

The Examination Hall.—Length 100 feet, width 68 feet, height 35 feet. This is designed with a flat roof, as not only in keeping with the style of architecture, but it affords an open terrace above it for the Library which is on the first floor.

The pillars supporting the roof would be either cast-iron on stone bases, or of stone or of brick plastered with fine chunam and marble polished. Iron girders would carry the roof in the usual way.

Light and ventilation is provided by doors at the side, and by upper windows placed under the projecting eaves, as well as by grated openings near the ground in the side verandahs; these could be closed at pleasure, but afford the means of a current of fresh air, while all glare is carefully excluded.

The Examiners would have easy access to the Principal's Room, which has been purposely made of a large size to meet any occasion of this sort or meetings of Committee, &c. The Students would occupy the body of the hall in front of the examiners, the spaces between the pillars and the walls serving as passages.

Entrance Hall.—Length 68 feet, width 30 feet, height 35 feet. Leaving the Examination Hall one passes into a covered space 68 feet × 30 feet, designed as an Entrance Hall, to afford protection at all seasons from the sun and weather to the numbers who might frequent the Examination Hall, or be obliged to wait near it. It has the advantage also of serving as an extra Lecture Hall should occasion require.

Passages lead off from this place to the bath rooms, which are situated, so as not to intercept the breeze, and are out of the way of observation.

Two staircases each 6 feet wide lead from this hall, one on either side of the large arch, to the

Library,
European Professor's Room,
Native Professors' „

these rooms will be noticed hereafter.

From this hall easy communication can be had with any part of the

building, and it has been designed with the object of convenience, ventilation, and extra space.

In the upper portion of the end walls would be a series of narrow windows to admit light and afford a fresh current of air, and as the hall is open at the four corners in addition; it is believed, that it would prove a cool and pleasant place protected entirely from the sun and weather.

Lobby.—38 feet × 38 feet. Passing from the Entrance Hall to the Lobby, one stands immediately under the dome, on one side is the undergraduate's room, on the other is the office. The space is 38 feet × 38 feet, looking up, at a height of 19 feet, one sees small ornamental projecting balconies in the two professor's rooms which are situated over the office and graduates' rooms; there is also a clear view up to the top of the dome, the lights in the lantern of which, are so arranged as to exclude as much as possible the direct rays of the sun, while allowing a free current of air.

It is convenient to have a space of this sort as a Lobby opposite the main entrance and in front of the office. It acts also as a good ventilating shaft up to the dome.

In front of the Lobby and rooms adjacent is a spacious verandah, and beyond this is an open terrace up to which carriages can drive, and which serves as a good reception place.

Office.—Length 38 feet, width 26 feet, height 17 feet. Is situated on one side of the Lobby, it is near the centre of the building, and is conveniently placed for the transaction of business or for reference.

Graduates' Room.—Length 38 feet, width 26 feet, height 17 feet. Is situated on one side of the Lobby opposite to the office, and is conveniently placed for access, while the graduates at the same time are not altogether removed from supervision, should it be necessary.

Class Rooms.—In number 8; each, length 38 feet, width 26 feet, height 25 feet. The eight class rooms have been arranged four on either side of the main entrance. This arrangement keeps certain classes distinct, and it prevents overcrowding at times of ingress and egress. While each room has a thorough draft; a point so essential in this country.

The two centre rooms of each range are made 3 feet higher than the side rooms, as it adds to the general appearance, and makes a better proportion in the height, if the two rooms are ever made into one. As it might be necessary to do this for lectures or other purposes, sliding doors are provided in the partition wall which separates them.

The rooms are provided with 12 feet verandahs in front and in rear, not only to keep them cooler, but these as well as the covered spaces at the end of each range, afford shelter from the weather and places where the students, if necessary, can leave their shoes. The end porches will shelter carriages.

It is desirable in this country to have plenty of light without admitting glare or the sun's direct rays. It will be observed that the upper windows in these class rooms are so arranged and protected, and in such a way as to add to the general appearance.

Each class room is so arranged that the students of any room can enter or leave it without having to pass through other rooms.

European Professors' Room.—Length 33½ feet, width 26½ feet, height 20 feet. Ascending the staircase in the Entrance Hall, one reaches at 18 feet a landing, by which one passes to the Professors' Rooms, the European Professors' Room on one side of the dome, and the Native Professors' Room on the other side. They are similar in all respects, and are situated thus to be away from the students' class rooms, and adjacent to the Library. Each room has a spacious verandah in front on the south or sunny side. The passage at the head of the stairs also leads to separate Bath rooms, situated over the bath rooms on the ground floor, and provided with a small circular staircase.

An opening with projecting balcony admits light and air from the dome.

Native Professors' Room.—Length 38½ feet, width 26½ feet, height 20 feet. Is similar in all respects to the room provided for the European Professors, and the same remarks apply.

Again ascending the staircases, which are 6 feet wide, with a rise of 6 inches for each step, one reaches the Library.

Library.—Length 68½ feet, width 30½ feet, height 24 feet. It is situated over the entrance hall, and will be a quiet place of retreat above the noise of the students below. Part of the day it will be in the shade of the dome.

There will be a verandah on the other three sides which are open to the light and breeze, and in front one can walk on the terrace which forms the roof of the Examination Hall.

The inside will be fitted with the usual cases for books, and in one of the corners it is proposed to have a lift, so that books may be sent up or down without trouble.

mortar joints not to be above ⅜-inch thick, and the seams to be left open on the face. No dry or hollow spaces to be allowed, but the interior is to be well grouted and filled in solid. All walls are to be carried up regularly. All arches to be formed on properly framed centres, the joints not to be more than ¼-inch thick. Relieving arches to be turned over all flat openings. The mortar to consist of the best ghooting lime, and of well burnt finely pounded and sifted brick dust, as may be directed by, and to the satisfaction of the Engineer in charge. If coloured bricks can be had, it would add to the appearance in some parts.

Plaster.—To be composed of stone lime if procurable and clean sand, or well burnt finely pounded brick dust as may be directed, with a little water lime. It is to be laid on the walls about ½-inch thick, and is to be properly smoothed and rubbed—the wall to be well cleaned, the joints being picked out, and the surface being wetted before the plaster is used.

Whitewash.—To be composed of stone lime, water lime, and shell lime, in the proportions which may be directed.

Marble plaster polished.—The outer surface of the domes and walls all round the inside of rooms should be polished for about 3 feet in height; when properly executed, it presents a surface like pure white marble, and in the case of rooms adds much to the general cleanliness and appearance. The method pursued in carrying this out will be furnished hereafter if necessary; at present, it is unnecessary to describe a long process. Where marble is easily procurable, it costs about Rs. 5 per 100 sq. feet extra.

Roof.—To be terraced, the under layer of tiles to be laid in parallel rows, the upper layer to be laid diagonally with one inch of fine mortar between the layers, the concrete to be of the following proportions—

2 parts best stone lime,
1 part fresh burnt brick dust,
3 parts of the hardest and best burnt bricks broken to size of a walnut, not larger.

The lime and brick dust to be made into a strong mortar, and well tempered with the usual quantity of water, before the broken bricks are added to it. The latter to be well wetted before being used, the whole to be thoroughly mixed and levelled before being beaten. A grouting of lime to be then laid on and allowed to soak well in.

The girders may be of iron or wood, with joists of wood or T-iron, calculated to bear 120 lbs. per superficial foot as the weight of roof.

Woodwork.—To be of sound well seasoned timber, free from all sap, knots, cracks or defects, of such scantling as may be required, and to be properly dressed, fitted and fixed.

Doors and windows to be provided with English made fittings.

Stone floor.—The stones are to be of uniform size and shape, evenly dressed at the edges, and set with close joints on a bed of 1½-inch mortar, the surface being properly smoothed and rubbed with coarse sand.

Marble floor.—In the Lobby, the circular portion of floor under the dome, to be of black and white marble alternating, and radiating from the centre stone, which will be of white marble.

Cutstone work.—All steps, string courses, brackets, sunshades, pillars in verandah, and similar positions; balustrades, chujjahs or eaves, copings, wall plates, bed stones, to be of Chunar or other suitable stone, to contrast with the general colour of the brickwork if possible.

Abstract Estimate.

c. ft.		RS.
94,769	Excavation, at Rs. 3 per 1,000, ...	284
43,081	Stone and brick concrete, at Rs. 12 per 100, ..	5,170
35,337	Foundation of brick and lime mortar, at Rs. 20-8 per 100, ...	7,244
38,203	Plinth of brick and lime mortar, at Rs. 20-8 per 100,	7,832
2,56,366	Brick in lime mortar, 1st floor, at Rs. 22-8 per 100,	57,682
11,248	" " above 24 feet, at Rs. 25-8 per 100,	2,868
43,336	Arch masonry, at Rs. 25 per 100, ...	10,834
r. ft.		
8,338	Cornice up to 12″ projecting, at Rs. 0-12-0 per foot,	6,253
2,650	Balustrade with baked earthenware, of lime masonry, base and cap 4 feet high, at Rs. 1-8 per foot, ..	3,975
s. ft.		
2,04,811	Súrkí plaster beaten, at Rs. 3 per 100, ...	6,144
1,54,119	White-washing, 2 coats, at Rs. 0-4-0 per 100, ..	385
4,284	Roofing Examination Hall, at Rs. 90 per 100, ..	3,856
57,786	" " at Rs. 20 per 100, ..	11,557
46,806	Flooring of Chunar stone slabs in mortar, 18″ × 2″, over two bricks flat, at Rs. 20 per 100, ...	9,361
1,444	Marble flooring slabs, at Re. 1 per foot, ...	1,444
c. ft.		
2,152	Burdwan stone wall plate, at Rs. 3 per foot, ..	6,456
840	" bed stone, at Rs. 3 per foot, ...	2,520
s. ft.		
6,377	Doors ¼ pannelled and ¾ glazed, at Rs. 1-12 per foot,	11,160
408	Trellis work, at Re. 1 per foot, ...	408
	Carried over, ..	1,55,433

No.		RS.
	Brought forward, ..	1,55,433
9	Finials, at Rs. 20 each, ...	180
r. ft.		
316	String course, at Re. 1 per foot, ...	316
125	" " ornamental, at Rs. 5 per foot, ..	625
s. ft.		
10,153	Marble plaster, polished, at Rs. 5 per 100, ...	508
No.		
36	Sunshades, at Rs. 20 each, ...	720
790	Bracket sizes, at Rs. 10 each, ...	7,900
166	Cut-stone pillars, at Rs. 128 each, ...	21,248
c. ft.		
3,309	" steps, at Rs. 3 per foot, ...	9,927
s. ft.		
13,776	" chujja, at Re. 1 per foot, ...	13,776
	Total, ...	2,10,633
	Contingencies, at Rs. 5 per cent., ...	10,532
	Grand Total Rs., ..	2,21,165

S. S. J.

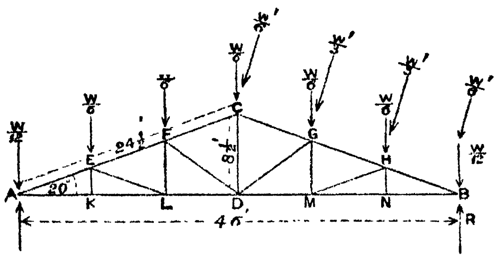
No. CCXXIII.

CALCULATIONS OF STRENGTH OF TRUSSES FOR RE-ROOFING MONTGOMERY HALL.

[*Vide* Plates XX. and XXI.]

By RAI KUNHYA LAL BAHADUR, *Assoc. Inst. C.E.*, *Exec. Engineer, Lahore.*

Calculations of Strength of Trusses for re-roofing Montgomery Hall.



Span of truss 46 feet. Rise $8\frac{1}{2}$ feet.

Average interval of trusses from centre to centre 5 feet.

Vertical Load, consisting of the weights of roof covering (corrugated iron, No. 18 B. W. G.,) truss frames, and ceiling, ..	40 lbs. per. sq. ft.
Normal Load, consisting of wind pressure, acting normal to the roof surface, on one side of the roof at a time	30 ,,
Total Vertical Load $= W = 40 \times 5 \times 24\frac{1}{2} \times 2$, ...	9,800 ,,
Total Normal Load $= W' = 30 \times 5 \times 24\frac{1}{2}$, ... =	3,675 ,,
Reaction at the wall due to Normal Load $= R = W\,(1 - \frac{1}{4}\sec^2 20^\circ)$ .. .. =	2,635 ,,

1*st.* Compressive Strain on Rafter.

The lowest segment AE or HB, $8\frac{1}{3}$ feet in length, is under the greatest strain, and since it is practically expedient to keep the rafter of uniform section throughout, therefore, calculating the strain on AE or HB, we have,

Strain due to Vertical Load $= \frac{5}{12}$ W cosec 20°, $=$ 11,938·75 lbs.

„ „ Normal „ $= \left(R' - \frac{W'}{6}\right)$ cot 20°, $=$ 5,556·55 „

Total strain, compressive, .. $=$ 17,495·36 „

$\therefore$ Area (by Gordon's Formula) $= \frac{17495}{\frac{5860}{10}} \left\{1 + \frac{16}{9} c \left(\frac{l}{d}\right)^2\right\}$ *one end fixed* and one end *free.*

(c being equal to $\frac{1}{250}$ for wood) $= \frac{17495}{586} \left\{1 + \frac{16}{2250} \left(\frac{100}{8}\right)^2\right\}$

$= \frac{17495}{586} \times \frac{19}{9} = 63$ square inches

$= 8'' \times 8''$, very nearly.

But, allowing for mortise holes, &c., the scantling should be 10″ × 8.″

2*nd.* Tensile Strain on the beam AB.

Strain due to Vertical Load $= \frac{5}{12}$ W cot 20°, .. $=$ 11,223 lbs.

„ „ Normal „ $= \left(R' - \frac{W'}{6}\right)$ cosec 20°, $=$ 5,913 „

$\therefore$ Total strain, tensile, .. $=$ 17,136 „

$\therefore$ Area $= \frac{17136}{700} = 24{\cdot}48$ square inches.

Making an allowance for the area cut by mortises, scarfs, &c., and the weight of ceiling to be borne directly by the tie-beam, it is proposed to make it 14″ × 8″. Net area at scarf is equal to $\frac{14}{3} \times 8 = 37$ square inches, which is ample, the area required being only 24·48 square inches, as per above calculations.

Some extra strength will, also, be imparted by the struts for fixing curved ribs, shown in section of truss, which will prevent the tie-beam from sagging in any way.

3*rd.* Tensile Strain on King-post CD.

Strain due to Vertical Load $= \frac{W}{3}$, ... $=$ 3,266 lbs.

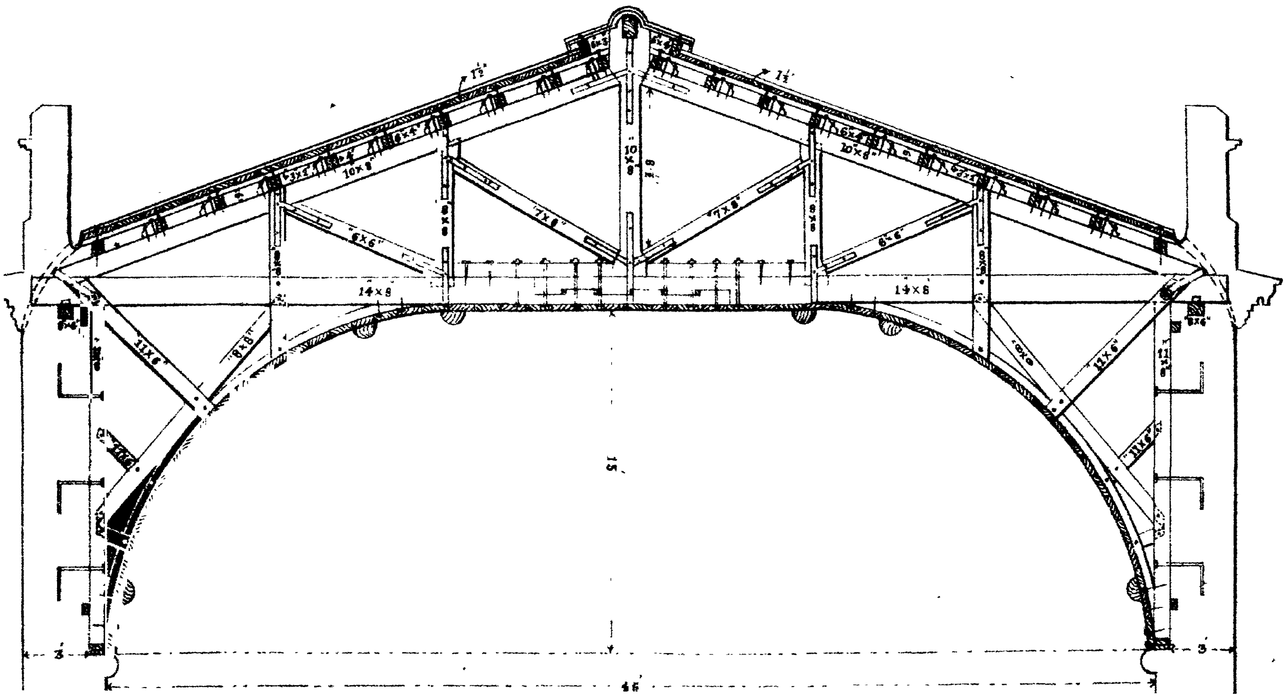
„ „ Normal „ $= \frac{W}{3}$ sec 20°, .. $=$ 1,304 „

Total strain, tensile, .. $=$ 4,570

$\therefore$ Area $= \frac{4570}{700} = 6{\cdot}53$ square inches nearly.

TRUSS FOR RE-ROOFING MONTGOMERY HALL.

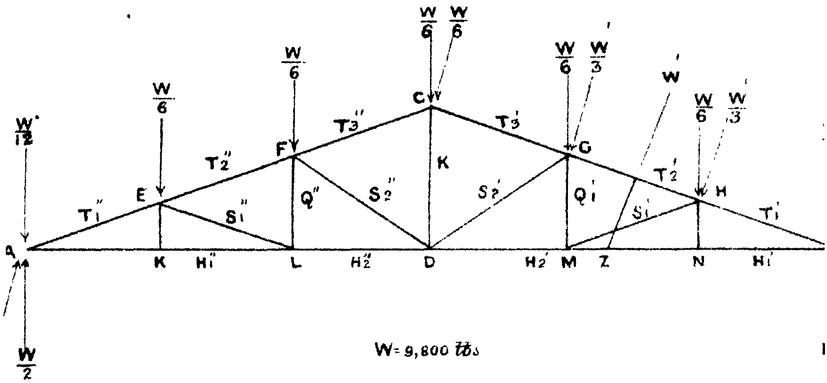
Scale—7½ feet = 1 inch.



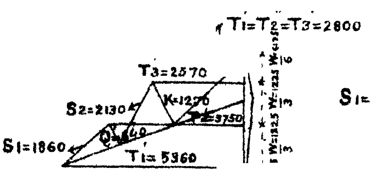
TRUSS FOR RE-ROOFING MONTGOMERY HALL.

FRAME-DIAGRAM OF TRUSS

Scale—10 feet = 1 inch.

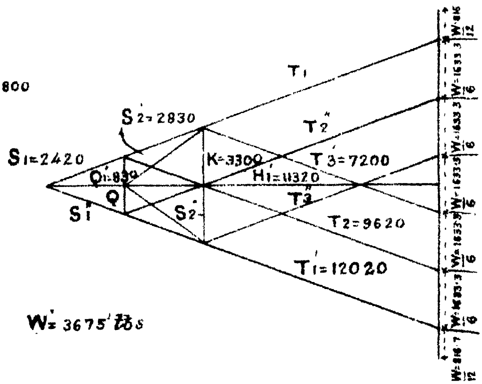


NORMAL STRESS-DIAGRAM



VERTICAL STRESS-DIAGRAM

Scale—5000 feet = 1 inch.



CALCULATION OF TOTAL WORKING STRESSES

Bars	Reference to Fig.	Stress.	Stress in Pounds: Due to Vertical Load.	Due to Wind: Greatest	Due to Wind: Least	Total Working Stress in pounds	Character of Stress.
Foot Segment, ...	HB or AE	T_1' or T_1''	12,020	5,360	2,800	17,380	Thrust
Middle „ ...	HG or EF	T_2' or T_2''	9,620	3,950	2,800	13,570	„
Top „ ...	GC or FC	T_3' or T_3''	7,200	2,800	2,570	10,000	„
Outer Segment, ...	MB or AL	H_1' or H_1''	11,320	5,690	2,300	17,010	Tension
Middle „ ...	MD or LD	H_2' or H_2''	9,040	3,980	...	13,020	„
Struts, ...	MH or EL	S_1' or S_1''	2,420	1,860	...	4,280	Thrust
Struts, ...	DG or FD	S_2' or S_2''	2,830	2,130	...	4,960	„

But as, the King-post has, also, to bear the weight of the tie-beam, &c., it is proposed to make it 10″ × 8″.

4*th.* Tensile Strain on Queen-post FL or GM.

Strain due to Vertical Load $= \frac{W}{12}$ .. .. .. = 816 lbs.

" " Normal " $= \frac{W'}{6}$ sec 20°, ... = 652 "

Total strain, .. = 1,468 "

$\therefore$ Area $\frac{1468}{700} = 2$ square inches.

Owing to practical reasons, it is proposed to make it 8″ × 8,″ which will suffice.

5*th.* Queen-post EK.

Same as FL, or 8″ × 8″.

6*th.* Strut FD or GD. Length 8 feet (upper strut).

Compressive Strain,

Due to Vertical Load $= \frac{W}{12}\sqrt{4 \times \cot^2 20^\circ}$, .. = 2,768 lbs.

" Normal " $= \frac{W'}{6}\sqrt{4 \sec^2 20^\circ + \operatorname{cosec}^2 20^\circ}$, = 2,211 "

Total strain, ... = 4,979 "

$\therefore$ Area (by Gordon's Formula) $= \frac{4979}{586} \times \left\{1 + \frac{4}{250} \times \left(\frac{96}{6}\right)^2\right\}$ (both ends free) = 43·29 square inches; should be 7″ × 7.″

7*th.*—Strut EL. Length 7 feet.

Compressive Strain,

Due to Vertical Load $= \frac{W}{12}$ cosec 20°, ... = 2,388 lbs.

" Normal " $= \frac{W'}{3}$ cosec 40°,.. .. .. = 1,914 "

Total, .. = 4,302 "

$\therefore$ Area (by Gordon's Formula) $= \frac{4302}{586} \times \left\{1 + \frac{4}{250} \times \left(\frac{84}{6}\right)^2\right\}$ (both ends free) = 30·36 square inches; should be 6″ × 6″.

8*th.* Purlins, span = 5 feet.

Interval from centre to centre = 3 feet.

Weight at 70 lbs. per superficial ft. at centre $= \frac{5 \times 70 \times 3}{2}$, = 420 lbs.

Strength of a piece 6″ × 4″ $= \frac{6^2 \times 4 \times 300}{10 \times 5}$,.. .. = 864 "

The scantling 6″ × 4″ will, therefore, suffice for the purlins. Therefore, the dimensions of the several pieces stand as follows :—

Principal rafter, ...	10″ × 8″
Tie-beam, ...	14″ × 8″
King-post (in the middle), ...	10″ × 8″
Queen post (FL) ,, ...	8″ × 8″
,, ,, (EK), ...	8″ × 8″
Strut (FD), ...	7″ × 7″
,, (EL), ...	6″ × 6″
Purlins, ...	6″ × 4″
Common rafters, ...	3″ × 2″
Ridge pole, ...	7″ × 4″
Wall plates, ...	8″ × 6″
Pole ,, ...	6″ × 4″
Purlin blocks, ...	12″ × 6″

K. L.

No. CCXXIV.

MADRAS PATTERN OF VENETIAN BAR.

[*Vide* Plates XXII. and XXIII.]

Description of the new 'Madras' Pattern of Venetian Bar, designed by ROBT. J. BALDREY, ESQ.

Madras, 26th August, 1876.

THE drawings in the Plates represent a pattern for a Venetian Bar designed sometime ago by me, and which has been favorably reported on by District Engineers in the Madras Presidency.

The merits of the design are considered as follows :—

Simplicity of construction.

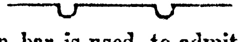
Cheapness.

Durability.

Economy in the scantling of door and window frames when glazed and venetian shutters are together used.

The dispensing with the bar from the middle of the venetians.

The easy detachment of the bar from the venetians, as they are held together by screws only.

The bar lying close to, and being on the same plane as that of the framework of the door, a *straight* iron fastening-cross-bar can be used, obviating the necessity of bending or providing  returns as in the case where the ordinary venetian bar is used, to admit of its being included in the fastening.

Besides, the screws and flat iron being English made, they are of a better finish and are also easily obtained in any market, whereas the hinged double staple used in the ordinary bar is made in the country, and at times so imperfectly manufactured, as to be easily injured in use, and when so, it is with difficulty extracted, invariably injuring the venetian, as it is driven in with a hammer.

Brass bars have been used in the Railway Central Station at Madras with advantage. I have used both brass and iron in the construction of the bar, and after many years have not had occasion to repair the venetians: they work remarkably smooth and noiselessly.

R. J. B.

The following extracts bear testimony to the advantages of this system over that hitherto in use.

Extract from an official letter by a District Engineer.

"I have the honor to report (for the information of the Secretary to Government, P. W. Department) that the Venetian bar designed by Mr. Baldrey was fixed to some new venetian windows put in the Church at Palamcottah. I find that the bar answers very well; the adoption of this bar enabled me to fix the venetian windows to the old frames, (originally made *only* for glazed windows,) which would have been impossible had the bar been of the ordinary pattern, except by the addition of extra battens to the sides of the frames."

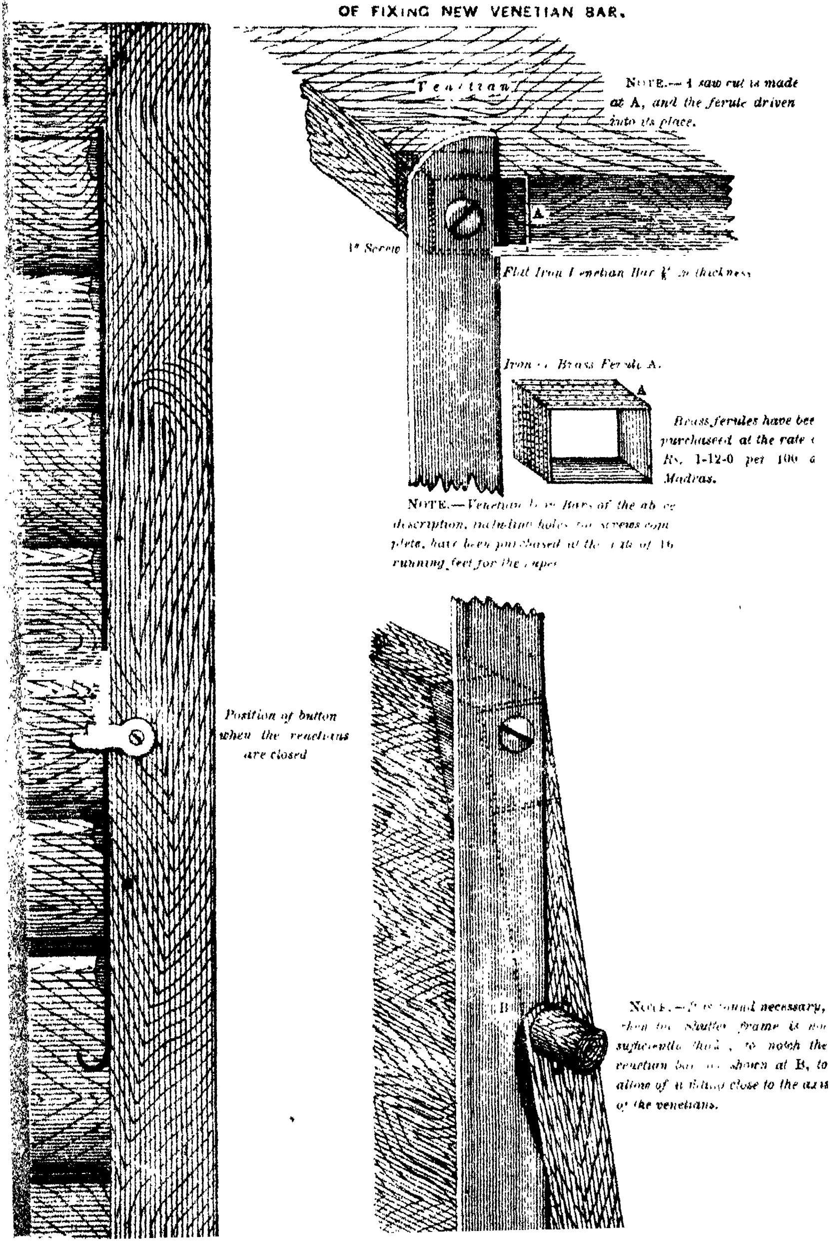
Extract from Circular by the Secretary to Government, P. W. D., Madras.

"The superiority of Mr. Baldrey's design over that of the Bengal pattern, now in use, appears to be its simplicity of construction, cheapness and durability. The dispensing with the bar from the middle of the venetian is a decided improvement, but the principal advantage of the design is a considerable saving of timber in the framework, for when glazed and venetian shutters are used together, the depth of the door and window frames is reduced by more than three inches.

"Mr. Baldrey has for some time used the new pattern bar, and has found it to work remarkably well, the motion of the venetians being easy and noiseless, and in every other respects satisfactory."

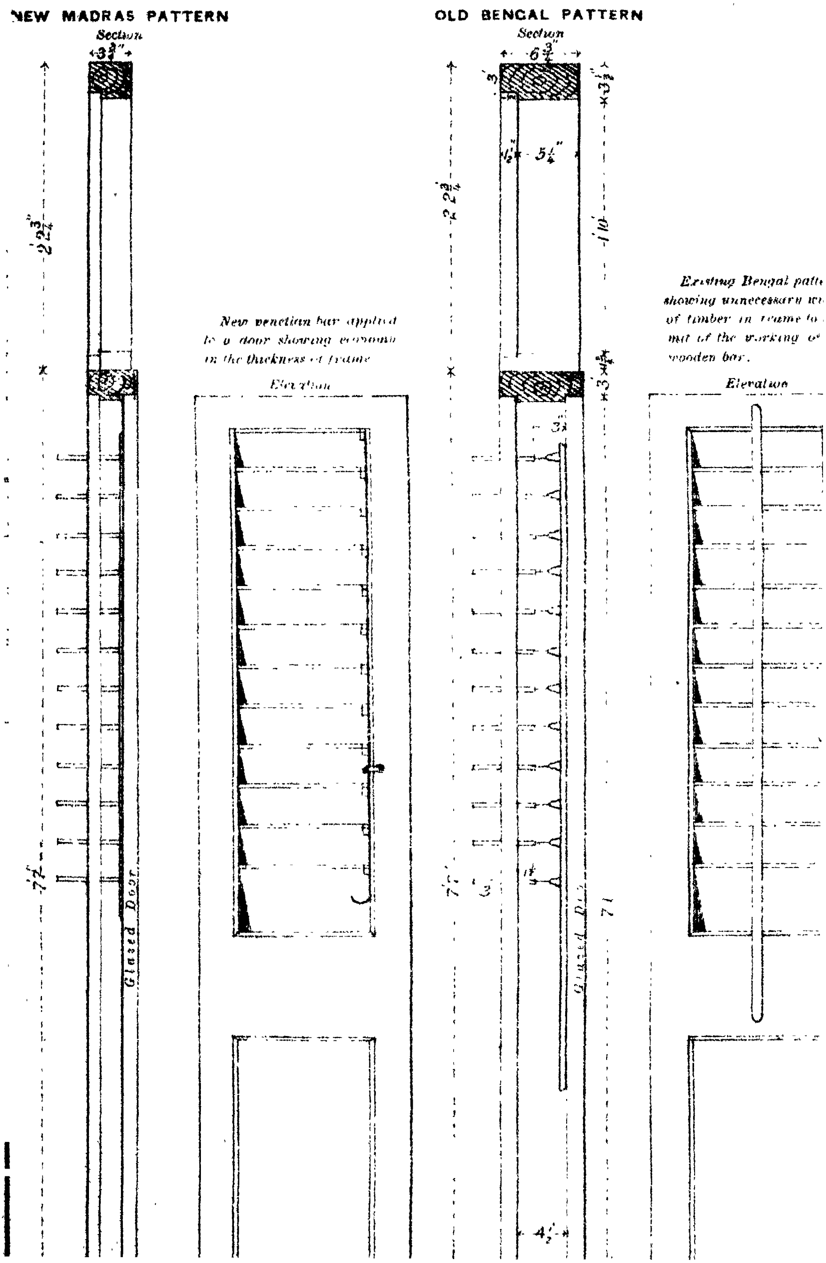
C. A. O.

DETAILS (FOUR-FIFTHS FULL SIZE) OF MODE OF FIXING NEW VENETIAN BAR.



MADRAS PATTERN OF VENETIAN BAR.

Scale. ⅜ inch = 1 foot.



No. CCXXV.

KANKAR LIMES AND CEMENTS, BARI DOAB CANAL.

Extracts from Reports and Letters on Kankar Limes and Cements on the Bari Doab Canal. BY A. NIELLY, ESQ., *Assist. Engineer,* T. HIGHAM, ESQ., *Exec. Engineer, and* COL. H. A. BROWNLOW, R.E., *Supdg. Engineer,* 1870-75.

I. REPORTS A, B, C, D, E, F, BY A. NIELLY, ESQ., ASST. ENGINEER.

Report A, dated 5th October, 1870.

THE following report relates to the experiments made by me on concrete blocks, on the results of these experiments, and on the preparations made for manufacturing four cubic feet stones, intended for the new falls and floorings which are to be part of the remodelling of the Bári Doáb Canal.

Being accustomed to manufacture stone chiefly with sand, my first care on arriving in the Punjab was to study that important ingredient; but I found at Umballa along the line of the Railway from Umballa to Lahore, at Amritsar, and along the Bári Doáb Canal, that sand was so fine, so completely deprived of sharpness, and so full of mica, that I had to condemn it as unfit for the manufacture of stone. I studied also as many samples as I could procure of limes produced by lime stones; but I could not discover in them those eminently hydraulic and cementing qualities necessary for the manufacture of concrete blocks. It was during these discouraging studies that I was ordered to leave Umballa and to report myself at Amritsar to Captain Palmer, Exec. Engineer, Bári Doáb Canal. I must mention here that during my short stay at Umballa, I had occasion to examine some fair specimens of concrete* made up by Captain T. C. Manderson, R.E., Exec. Engineer, Lower Sirhind Division, but their composition remained a secret from me. During my visit

* Artificial stone.

to Captain Palmer at Amritsar, his brother, Mr. E. C. Palmer, Exec. Engineer, had the kindness to draw my attention to his experiments on kankar blocks, and to allow me to visit the excellent specimens he had manufactured. This visit, and the bad opinion of sand which Mr. Palmer had, an opinion which corroborated mine, convinced me that kankar, with which the Punjab has been so abundantly provided, was, in these parts of the world, the real base of concrete blocks; and that after the experiments already made by Mr. E. C. Palmer, the only task which remained to be done by me was to improve the manufacture, and to try to explain the action of the burnt kankar.

Having then been appointed to the Special Works of the Bári Doáb Canal, and having been sent to Kallair and Mádhopur to see what I could do for the manufacture of concrete blocks; I started from Amritsar on the evening of the 3rd of May, and on the 7th of the same month I wrote the following report:—

Report No. 1, dated 7th May, 1870.—I have visited at Kallair the works where the concrete blocks are manufactured, and after carefully studying the ingredients employed, and the details of the manufacture, I wrote the following report, which I hope will throw some light upon the usefulness of kankar and the *rôle* it is called to play among the principal ingredients with which mortar, concrete and béton are made.

I shall divide this report into two subjects,—the first shall treat of the materials with which kankar stone is made; the second shall treat of the manufacture.

Materials.—The first enquiries I made were about the nature of ingredients used at Kallair, and the quantities employed. I remarked that what was pointed out to me as kankar lime was kankar burnt in a rude way, then broken to a rough powder, and afterwards mixed with broken raw kankar and water in the way generally used by natives, that is to say, with a great deal more water than necessary. The quantities employed were, I was told, one of the powder of burnt kankar to two of broken kankar, but nobody would show me in what the quantities were measured.

There exists in France a sort of natural formation named psammite, which, being composed of grains of quartz, schist, felspar and mica, mechanically agglomerated by a clayey and ferruginous cement, bears, I believe, a great resemblance to kankar. This psammite, half-burnt in a lime-kiln with a free access of air, produces one of the most energetic artificial puzzolanas, and is used for hydraulic works in places where water does not contain any salt. Being, therefore, under the impression that psammite and kankar were likely to have the same properties, I tested with muriatic acid the so-called kankar lime, and I found that, like artificial puzzolana, it effervesced strongly, instead of being insensible to the action of the acid, as it should have been had it been real lime.

I concluded from this experiment and from the qualities which kankar is well known to possess, that this mineral half-burnt is an energetic puzzolana, and that it was sufficient to mix with it from $\frac{1}{3}$ to $\frac{1}{2}$ of good fat lime to obtain a good hydraulic mortar.

The proportions for stone will probably be—

$\frac{1}{6}$	cubic foot	fat lime,	} = one cubic foot stone.
$\frac{1}{3}$	,,	half-burnt kankar,	
1	,,	broken raw kankar,	

As some kankars contain much lime, the above proportions should vary accordingly.

Manufacture.—The manufacturing of the stone at Kallair is what may be called the infancy of the art of stone-making. The half-burnt kankar and the raw kankar were broken in the most wasteful and rude way; the mixture with water was made under the direct action of the sun's rays; the moulds, made too light, were out of shape; the rammers were so light, the mixture so wet, that after half an hour or more ramming the last layer was far from having obtained the hardness required. Each man made about $\frac{2}{3}$rds of a cubic foot per day, whereas he should make at least from 6 to 8 cubic feet (22 was the number of cubic feet made in eight hours by each convict at Algiers). No layer was raked so as to be joined to the next layer, and the stone commenced, instead of being completed in the same day as it ought to be, took three days to manufacture. As a necessary consequence of this rude manufacturing, the stone produced is very deficient in shape, and is scarcely fit for foundation work.

However, all these defects may be easily cured with proper moulds and rammers, and properly instructed supervisors. The greatest difficulty to contend against will be the careless way with which the coolies work, the sitting posture they have been allowed to adopt, and which must be changed for an upright posture, and the lightness of the rammers which must be changed for much heavier ones. The best way to prevent carelessness will be, I think, to write upon each stone the name of the coolie who made it, and to inflict on him some pecuniary punishment if the stone turns out to be bad.

As for the improvements to introduce in the tools and manufacture, I would suggest to get the half-burnt kankar reduced to powder with a road hand-rammer striking on an iron plate one inch thick, one and a half foot square, sunk a little in the ground. The powder so crushed would be sifted through such a sieve as may be procurable at the Mádhopur Workshops.

A similar arrangement would do for breaking the raw kankar. The lime and kankar puzzolana should be mixed as intimately as can be done with a shovel, then moistened until they form a thick mortar, and last thoroughly worked with the raw kankar from which the earthy matters should have been washed as well as possible. The whole of the above work, except the washing, should be carried out under shelter if practicable.

I will not enter into the minute details of the remainder of the manufacture, as it would be to repeat to a great extent the recommendations which are to be found in my pamphlet on stone-making (Coignet's system). I will only say that I hope to be able before long to prove by experiments the vast usefulness of kankar in the erection of hydraulic works.

A few months after the above report was drawn up, I received a printed document written by J. E. Tanner, Esq., C.E., and addressed to the Supdg. Engineer, Sirhind Canal. In this report I was happy to find that long before me that Engineer had stated that the composition of the burnt kankar brought it under the head of puzzolana. As, however, Mr. Tanner does not give us a complete analysis of kankar, and as I think it is important that the composition of kankar in its raw and burnt state should be known, I join to this report a letter in which I beg to be allowed to send samples of various kinds of kankar and kankar lime to the nearest Government chemist, so as the question of composition may be set at rest. The knowledge of the composition of our kankar lime will enable me to fix with certainty the quantity of stone lime necessary to be mixed with it to render it eminently hydraulic.

As regards the manufacture, I have had occasion to remark that the means I recommend for breaking the raw kankar and pounding the kankar lime were not satisfactory. I believe, now, that the best mode in the absence of machinery will be to do like our súrki pounding, that is, to give out that part of the manufacture to petty contractors.

Having returned from Kallair to Mádhopur, and compiled the report No. 1, I ordered at the Workshops the tools and moulds necessary to make experimental concrete blocks. On about the 17th May, these things were delivered to me, and I set to work immediately.

The lime I could get at Mádhopur was poor in my opinion. However, I made two samples of blocks; the first of these is useless, the proportion of mortar being too small; the second is as good as any good masonry, but would not, I think, have set rapidly under water. I might have made it much stronger by doing like in Madras, that is, mixing some *gúr* to the water used for the mortar, or I might have rendered it hydraulic by mixing kankar lime to the stone lime, but I would not use any ingredient which was not readily procurable at Mádhopur. These two blocks being made up, I started for Kallair, where I made the first instalment of 17 stones 2′ × 1′ × 1′, as shown in the following statement. I wrote at the same time the report No. 2, which follows.

Report No. 2, dated 1st June, 1870.—I enclose a statement showing the number of experimental stones made by me from the 17th May to the 30th. It will be seen from a perusal of the above statement, that I have succeeded in making two men ram five cubic feet of stone each per day. As, however, I think that unless the men were subjected to a very strict supervision like convicts, it would not be possible to obtain the above amount of work every day; it will be better, therefore, to count upon four cubic feet only. I have not been able to ascertain yet the real rates of kankar at Kallair; but if it costs what I was told, viz., Rs. 9 per 100 cubic feet, the manufacturing of the stone there will be more expensive than anywhere else. The cost of 100 cubic feet of stone would be about as follows:—

	RS.	A.	P.
150 cubic feet raw kankar, at Rs. 9 per 100 cubic feet, ... =	1	8	0
100 „ „ burnt „ „ 13 „ „ ... =	1	0	0
Labour, including pounding lime and breaking kankar, ... =	[illegible]	6	0
Total,	35	14	0

I shall allow one month for the setting of the stones, and after that period of time I shall report on the various qualities and powers of the stones I have manufactured.

During the month of June I made 19 more blocks, which exhausted the small stock of kankar lime we had in hand.

On the 11th of July the blocks Nos. 1, 2, 14, 15 were placed under the influence of a strong current, and left there till the 25th of August. I would have liked to place these blocks immediately under the falls, but as they were not big enough to be immovable, I thought it might prove injurious to the masonry of the fall if I placed them there. The block No. 13 was placed in the water four hours after it was made up, and it was found on examination to have set, and to have hardened. The shape of all the stones made up in the mould I used was perfect. If, therefore, those blocks were placed close to each other, and joined by a thin coat of hydraulic mortar, they would form a solid mass which might be exposed without fear to great velocities.

I weighed nine of the blocks, and I found that the average weight of a cubic foot was 136 lbs.; this is about 30 per cent. more than a cubic foot of brick, but it is less by 27 lbs. than the cubic foot of stone made by Mr. E. C. Palmer. Whether this comes from our kankar which is very inferior to the kankar to be had at Amritsar, although ours is much dearer, or whether it comes from insufficient pounding, I will ascertain as soon as we begin making blocks again. I think that it comes from the kankar, as the average weight of the blocks made before my time at Kallair is the same as mine, and they had no end of pounding. The price of kankar has been reduced, and from Rs. 12 that I was asked at first, it has come down to Rs. 8. The cost of 100 cubic feet of stone is now as follows:—

	RS	A.	P.
150 cubic feet of raw kankar, at Rs. 8 per 100 cubic feet, ...	12	0	0
100 „ „ burnt „ at Rs. 12-8 per 100 cubic feet,	12	8	0
Labour, including pounding of lime and breaking raw kankar,	9	6	0
Total, ...	33	14	0

I will conclude by remarking that I do not think it necessary that the principal ingredient used should be raw kankar: as long as I can obtain kankar puzzolana and good fat lime, it is indifferent to me whether the third ingredient at my disposal is kankar, good sand, gravel or broken boulder. With each of these three last ingredients, I could, I think, obtain a good concrete stone, probably much heavier than the kankar stone. But kankar puzzolana is the only ingredient absolutely necessary in hydraulic works; it is the ingredient which mixed with fat lime contains all the hydraulic and cementing qualities so difficult to meet with and so much wanted.

APPENDIX TO REPORT A.

Statement showing the number of Experimental Stones made up, and all the details of their Manufacture.

Numbers marked on the stones	Dates of manufacture	Where made	Proportions	Remarks	Quantity of materials required for 2 cubic feet of stone	Results	Crushing weight per square inch
					c. ft.		lbs.
	17th May,	Mádhopur	½ cubic foot stone lime, 1 cubic foot burnt clay, 3 cubic feet broken boulder.	Insufficient mortar, ...	4·5	Bad	
	"	"	1 lime, 1½ burnt clay, 3 broken boulder.	...	5·5	Fair	
1	24th May,	Kallair ...	1 sifted burnt kankar, 2 broken kankar.	Made up in 1¼ hours by 2 men.	3·0	Good	860
2	26th May,	"	2 burnt kankar, 3 broken raw kankar.		5·0	"	
3	"	"		Made in one day by two coolies.	...	"	
4	"	"			...	"	
5	"	"			...	"	
6	"	"			...	"	1520
7	27th May,	"			...	"	
8	"	"			...	"	
9	"	"		As above.	...	"	
10	"	"			...	"	
11	"	"			...	"	
12	28th May,	"	½ cubic foot stone lime, 1 burnt kankar, 3 broken kankar.	...	4·5	"	
13	"	"		Deposited on the bank of the canal, and half sunk in water 4 hours after it was made up.	...	Quickly hardened.	
14	30th May,	"	⅓ cubic foot stone lime, 1⅕ burnt kankar, 3 broken kankar.	Made in one day by two men.	4·53	Good	
15	"	"			...	"	
16	"	"			...	"	
17	"	"			...	"	

Results of Experiments made on Cubes composed of Kankar Lime and various Ingredients.

Number on cubes	Composition	Age of cubes	Weight required for crushing per square inch	Weight required for cracking per square inch
1	Kankar lime, unrammed, ...	38 days	860 lbs.	...
12	" rammed, ...	34 "	1,520 "	...
2	" and washed kankar, ...	37 "	...	1,873 lbs

Report B, dated 20th February, 1871.

On the 5th October, 1870, I wrote a report, No. A, which contained a statement of the beginning of my experiments on kankar or concrete blocks. These experiments having been necessarily undertaken with kankar lime which had been burnt and pounded before my arrival, I could not expect, in the absence of chemical analysis, to find out at once the defects of the manufacture of kankar lime as carried out by the native contractors, and all the qualities of that lime when well manufactured. Therefore, kankar lime being required, I ordered that three small conical field kilns should be made up and burnt by experienced contractors, and I took advantage of this opportunity to study the manufacture of kankar lime.

The first of these kilns was burnt and the lime pounded whilst I was surveying on the Beas river. I examined some samples of the powdered lime obtained, and found that it was a poor stuff, evidently composed of ashes, underburnt and well burnt kankar, the product of the ignorance and bad faith of the contractor.

My work being then completed on the Beas, I had the two other kilns unloaded in my presence, and took care to have the well burnt kankar, the overburnt and underburnt carefully separated. The quantity of well burnt kankar being only one-half of the total load of the kiln, I was obliged to conclude that the amount of fuel required during the winter was ignored by the contractors, and that to conceal the results of their ignorance, they generally pounded together all what they could get out of the kilns, and produced consequently the poor stuff obtained by the first kiln.

On enquiry I find that the practice of spoiling kankar lime is general in the district, which explains why it is not more in use in these parts.

The proportion of úpla to kankar generally used is 2 to 1. I ordered to make a fourth kiln with the proportion of 3 to 1, and to cover the exterior surface of the kiln with a layer of ashes. I have unloaded the kiln made according to that order, and I find that the loss in underburnt kankar is only five per cent. of the load of the kiln.

The underburnt kankar being useless, I tried only the well burnt kankar and the overburnt.

As entering into the details of my experiments would make this report too long, I will state their result only.

Batála kankar lime is, as far as can be judged by its imperfect slaking and by experiments, a limit hydraulic lime, *i. e.*, that it may be classed between the eminently hydraulic limes and the inferior cements. It should, therefore, if thoroughly washed before burning, contain after combustion nearly equal quantities of carbonate of lime and combined clay. But the kankar being burnt, unwashed and covered with its coat of clay, it is likely that the quantity of clay in the pounded lime somewhat exceeds the quantity of carbonate of lime.

Therefore if it was desired to obtain a pure limit hydraulic lime, it would be necessary to wash the kankar before placing it in the kiln. But, as far as my experiments go now, they tend to prove that the extra quantity of clay is not injurious to the lime.

My experiments prove also—

1st. That if Batála kankar lime, well burnt, is finely pounded, made into a thick paste, and thrown in the water immediately after being made up into a ball, it hardens steadily so as it cannot be penetrated by a fine needle after a fortnight, and is hard enough after a month to bear my pressing it against a table, throwing on it as much as I could of my weight.

2nd. That if Batála kankar lime, treated as before, is allowed 20 hours' setting, and then placed in water, it is after the 20 hours hard enough not to be penetrated by a fine needle, goes on hardening under water, and is, after a fortnight, able to bear the pressure against the table.

3rd. That the mixture of one part stone lime with three parts kankar lime does not appear to improve kankar lime in any way.

4th. That overburnt kankar lime, treated as in No. 1, gets harder than No. 1 ball during the two first days, but remains after that lapse of time in a half hard, brittle state without improving.

Besides what I might call laboratory experiments, I have employed kankar lime in the following canal repairs, in places where its strength is sure to be most severely tried.

The two upper weirs of No. 13 cascade have been repaired with boulder masonry, the mortar being composed of one part kankar lime to one part stone lime. This mixture was made because the stock of kankar lime was very small, and I knew that the kankar lime would communicate its hydraulic properties to the stone lime. The deep holes of an ovoidal form hollowed by falling water in the masonry left abutment of the perendicular fall No. 17 were repaired with boulder masonry, the mortar being composed of two parts kankar lime to one part stone lime. Here he tenacity of the mortar will be excessively tried, as the new masonry rests on a slanting surface. In both cases the canal water was let on the alls about six days after the completion of the repairs.

Besides these useful works, I have placed in the weir, on the third day of No. 1 rapid, two stones, 2′ × 2′ × 1′, made as follows:—

Made on the 19th January—

One four cubic feet stone composed of { one part kankar lime coarsely pounded. two parts raw kankar washed.

The lime and the kankar were slightly wetted separately, then mixed together as thoroughly as can be done by hand labour.

Six and a half cubic feet of the mixture made one stone of four cubic feet. The stone was rammed 12 hours by two men. The rammers weighed 16 lbs.

Made on the 20th January—

One four cubic feet stone composed of { one part kankar lime coarsely pounded. two parts small stones from bed of canal.

Acted on as before.

Five and a half cubic feet of the mixture made the four cubic feet stone.

On the 24th these two stones were carried to Mádhopur, although one of them had only four days for setting, and the other three days, and although I could dispose only of weak coolies unaccustomed to move great weights.

The stones were weighed at the Mádhopur Workshops, and we found that—

The kankar stone weighed 143 lbs. per cubic foot, and that the stones made with small ones weighed 145·5 lbs. per cubic foot.

As the best concrete in England weighs about 140 lbs. per cubic foot, the above weights are satisfactory.

On the 21st January the stones were carried again to No. 1 rapid, and placed in the weir of that rapid.

The weights of the above stones are the greatest yet obtained. I ascertained it by weighing at the Workshops the best blocks made at Amritsar, and which were reported to weigh 162 lbs. per cubic foot. Their real weight is 136 lbs. only per cubic foot.

I am, therefore, in a position to cancel the remarks made in my former report when I compared the weight of the stones made by myself at Kallair, and the weight of the stones made at Amritsar, and to state that most of the former stones are equal in weight and superior in shape to any stone made before I commenced experiments.

I will conclude this part of my report by stating that having yet to ascertain mechanically the resistance to pressure of the mortar and béton made with Batála kankar lime, I am making now eight cubic inch stones, which will be sent to the Mádhopur Workshops as soon as they have attained their utmost hardness. This, I believe, will be after keeping the samples about six months under water.

I will pass now to the financial part of this report. As the kankar by being burnt loses at least one-third of its weight without losing anything of its bulk, by making the kankar lime at the bed, instead of manufacturing it at site of works, we shall save one-third of the cost of carriage: also kankar by being washed loses one-fifth of its weight; we shall, therefore, effect another saving on carriage by washing it at the bed. Finally, as with proper apparatus it is easier and cheaper to move blocks than loads of kankar, I shall suppose in the following calculations that the stones are manufactured at the kankar bed.

	RS.
Cost of Kankar Lime.	
Prime cost of kankar at site of bed, per 100 cubic feet, ...	3
Making and clearing the kiln, ...	3·5
Fuel (úpla)	2·5
Pounding of lime (coarsely), ...	2
Cost of lime per 100 cubic feet, ..	11
Cost of Washed Kankar.	
Prime cost of kankar, per 100 cubic feet, ...	3
Washing, ...	2
Cost of washed kankar per 100 cubic feet, ..	5
Cost of Kankar Stone.	
54·25 cubic feet kankar lime, at Rs. 11 per 100 cubic feet,	5·96
107·25 „ washed kankar, at Rs. 5 „ „	5·36
Pounding 100 cubic feet stone, first quality, ...	7·85
Total cost of 100 cubic feet stone, ..	19·17

We have to add to this the cost of carriage to site of work, supposing the stone to weigh about 140 lbs. per cubic foot, and the district rate to be one and a half pie per 82 lbs. per mile. The carriage would, therefore, be Rs. 1-5-4 per 100 cubic feet and per mile. In calculating the cost of lime, I have stated that the lime was coarsely pounded. I regret to say that without the help of machinery it is impossible to get the lime pounded as finely as it should be. I have, therefore, asked Mr. J. L. Watson, Exec. Engineer of the Mádhopur Workshops, to have the kindness to supply me with the design and estimate of a pounding machine of the simplest description which could be driven by cattle, and which can be employed also for pounding súrki and mortar. I have made a rough estimation of the work that could be done by it, and found that it will pound 100 cubic feet of lime at the rate of four annas, or one-eighth only of the actual cost.

In conclusion, I must state that having been informed that the Batála kankar beds were getting exhausted, every hydraulic engineer must feel a regret in seeing our only source of hydraulic cement wasted in making roads which cannot stand heavy traffic. It is true that new beds of kankar are often discovered, and I can mention one of excellent quality which has just been found at Bhímpur by Mr. W. G. Cotton, Exec. Engineer, 1st Division, Bári Doáb Canal. But whatever be the extent of our wealth in kankar, I think it would be wise to reserve some of the beds in the proximity of the canals, so as to keep up our supply of a lime, which when well worked, would be in every way much cheaper and much better than the stone lime hitherto employed.

If we do not take advantage of our only supply of natural cement and prevent its being wasted on roads, we shall be obliged to have recourse one day to artificial cement as recommended by Lieut.-Colonel Brownlow, R.E., who was not aware of the fine qualities of our kankar limes when manufactured with care.

P.S.—I find that the specific gravity of Batála kankar lime is 1·2; the specific gravity of Portland cement is only 1·4.

Report C, dated 15th October, 1871.

Part I. Giving every information about the Kankars along the Bári Doáb Canal from Mádhopur to Aliwal.

It seems at first sight of little importance to the engineering profession of India whether kankar is, according to Daniel Page, a superficial accumulation of calcareous matters, which, in point of time, seems to correspond with the boulder drift formation, or whether the surface waters of our own time continue to transport in their course calcareous matters which percolating through the soil, are still forming those beds of nodules that we are so anxious to find in the vicinity of our works. The question, however, is important in this way that, if nature does not in reality keep up that natural production of kankar, as these beds of nodules are our only sources of cements and hydraulic limes, it would be advisable to prevent the premature exhaustion by road-making of those which are close to our works.

Along the line of the Bári Doáb Canal, and at small distances from it, kankar is to be found at various depths, and of various chemical composition.

At Bhímpur, 15 miles below Mádhopur, it is to be looked for in the slopes of the watershed crossed by the canal at depths varying from 4 to 8 feet, and in masses from 25 to 50 cubic feet. In some spots it is of a compact but sandy nature, containing many fossils of marine shells and other detritus. In some other spots it is a calcareous nodule likely to be a fresh water deposit.

Two or three miles below Bhímpur, kankar becomes a flat stratified nodule, very compact and hard.

Three miles further on, abreast of Sirkián, and two miles eastward, deposits of the calcareous nodule are to be met with.

Kankar is not again found till Batála, where it is excavated from large beds at a depth of 3 or 4 feet, and in the shape of a very contorted nodule, containing clay in the empty spaces.

Beds of the same kind of kankar are crossed by the canal two miles below Kunjar, but they are at such depths as to be practically unworkable.

We have not had an opportunity of getting acquainted with the beds below Aliwál. Kankar from Vahn is the only kankar from the plains that we had occasion to analyze; it is found close to the surface of the ground, and is a much purer carbonate of lime than our kankars.

Table I. gives all the important information about the kankar beds, and also all what has been published about the kankars of other localities.

The full value of the analyses given in Table I. is not realised until we compare them to those given in Tables II. and III.

Table II. contains the analyses of well known stone limes, whose treatment as regards burning, slaking, nature, and proportion of ingredients for mortar, is well known, and need not, therefore, be repeated in this report.

Table III. is a translation of a table by Vicat, in which are classed all the varieties of hydraulic limes and cements by types, according to the quantities of carbonate of lime and combined clay they contain. The proportions of lime to clay are given both before and after combustion of the stone. This useful table enables us to see at once what name we can give to our kankar limes. For instance, we could call cements superior to the ordinary cements, the calcareous nodule of Pathánkot, Bhímpur (2), Jandhy Chouty, &c.; ordinary cements, washed Batála, Lucknow No. 3; cements inferior limits, the kankars of Vahn, Gházipur, Lucknow No. 1, and No. 2, &c. The Bhímpur sandy nodule ought to come under the denomination of poor cement, the best for concrete under water.

In conclusion of this part of our report, we must state that the analysis and information it contains have been given in imitation of the same kind of work done by Vicat for the whole of France. Vicat's labours in that direction were stated by a commisssion composed of the most eminent scientific men in France to have saved thousands of millions of francs to the French Government.

Part II. Giving the Result of Experiments on Batála Kankar Cement, burnt unwashed, used for Mortar and various kinds of rammed Concrete.

The Batála kankar used for mortar was burnt unwashed, the well-burnt cement picked out of the kiln and pounded by hand labour. However imperfect this pounding was, the cement used was not sifted, so as not to increase the cost. As reducing the cement to a fine powder has been proved to be necessary, we have given in a previous report the plan of a mill designed by Mr. J. L. Watson, Exec. Engineer, Mádhopur Workshops; this simple machine, moved by cattle, would pound the lime at one-eighth of the actual cost, and could be used for mortar-making.

With the cement mentioned above, the repairs of the boulder masonry of cascade No. 13 and perpendicular fall No. 7 were carried out, and stood well, although the canal water was rushing on them six days after the completion of the repairs. When the head of the canal was closed by the flood of the 23rd July, and the falls laid dry, the mortar was found very hard, and in a very satisfactory state.

Different proportions of stone lime were mixed with the cement, as one of stone lime to one of cement, or one of stone lime to two of cement; but having since analyzed the Batála kankar lime *burnt* unwashed, and found it to contain—

Caustic lime, 31 parts,

Combined clay, 69 parts,

we would now add 38 parts of caustic lime to each hundred parts of cement; or, to make it practicable, two measures of caustic lime to five of cement. This mixture if analyzed would give nearly equal quantities of clay and caustic lime, which is the best proportion of burnt cements according to Table III.

Neat Batála kankar cement was tried on a length of 40 feet of the weir built across the Ravi at Mádhopur. When this work was examined after the subsidence of the floods, it was found that the kankar cement was uninjured, although laid last, and although it was in the line of what was formerly the deepest channel;—whereas the stone lime mortar had been everywhere worn out to depths varying from 1 to 6 inches. In all the above works, the mortar was mixed with the smallest proportion of water possible, and was used immediately after being prepared; none being allowed to remain prepared in the evening for the following day.

To find the value of the kankar lime as a cementing material for concrete and artificial stones, about 115 blocks, 1′ × 1′ × 2′, were made at Kallair in the beginning of June 1870; the greater number of them being composed of two burnt kankar to three washed kankar; 80 of these blocks were placed in rapid No. 10 in July 1871, and they are now undergoing trial; 20 more are to be placed in the weir of the dam, and 5 placed in the weir of the dam built across the Ravi, although worn at their upper surfaces by the stream of boulders passing over them, have stood well during the flood. However, as the lime used for these blocks was made by natives before we took charge of the experiments, we do not feel as confident about the result they will give as we are about the other experiments.

In January 1871 two blocks one foot deep, offering together to the current an horizontal surface of eight square feet, were placed in the weir of No. 1 rapid five days after they were made up; a week after the canal water was running over them. In July of the same year the canal being closed, these stones were examined and found very hard, and in a very satisfactory condition. Their composition is—

1 Batála kankar cement burnt unwashed and coarsely pounded, but pure;
2 raw kankar washed;

And—

1 Batála kankar cement burnt unwashed and coarsely pounded, but pure;
2 small stones from bed of canal.

Except that no machinery was used, the manufacture of these stones was carried out as it is done in the Coignet's manufacture. They weighed a little more than the usual 140 lbs. per cubic foot, and required also as near as possible the usual proportion of 160 cubic feet of material to make 100 cubic feet of stone.

Besides the above stones, a few ornamental cornices of artificial sand stone were moulded, and a great many 9-inch little cubes were manufactured, and tried under the crushing machine at Mádhopur. Table IV. gives the crushing weights of specimens when five weeks and six and a half months old; all the dry specimens of the second trial had been left six months under water and then dried.

We have introduced in this table a new feature in the way of experiments, which is the crushing weights of the specimens when saturated with water.

Table IV. gives also the percentage of water absorbed by each kind of specimen.

The examination of the table gives rise to the following remarks:—The crushing weight obtained for the unrammed kankar cement shows that it is quite equal to the natural cements known in England as Roman cements; its strength nearly doubled in six months under water.

Specimen II. illustrates the effect of ramming, and shows that neat cement out of water could stand the highest pressure obtained.

Second to it in strength out of water comes specimen III., but both specimens II. and III. are beaten in water by specimen IV.

Specimens V. and VI. are composed of the same materials and in the same proportions; but the mixture in V. is unground, and in VI. it is well ground in a stone-mill. The grinding was employed for two reasons —*1st*, to reduce the numerous slates of mica to fine powder; *2nd*, to break the rounded grain of sand so as to make each new grain sharper though smaller. The crushing weights after five weeks did not show that the grinding was an improvement; but, as it always happens to slow-setting material, after six months in water the strength of No. VI. was found to have doubled, and it took the second place as far as strength under water is concerned. The ground sand mixture is the most easy to mould and to ram.

The ground sand mixture was used to cement a double quantity of split boulders, and to compose specimen VII., which proved to be of a very fair strength under water, although containing two-fifteenths of cement only.

Specimens VIII. and IX. give fair results, but they do not come up to the others, except the unground mixture of cement and sand.

Specimen X. has been chosen among the best of our well-burnt bricks, and it was kept also six months under water; but its strength, especially under water, proved to be much below the strength of the specimens of concrete.

The conclusion we arrive at is as regards Batála kankar cement burnt unwashed, that the concrete made of one kankar lime to two washed kankar is the best for superstructure, whereas the best material for works under water is the artificial sand stone when the mixture is ground.

Table I.

FROM MADHOPUR TO ALIWAL.

Names of Localities	Nature of Nodule	Analyses of raw kankar: Carbonate of lime	Combined clay	Uncombined sand	Whether scanty or abundant	Kinds of kiln and fuel already tried	Slaking	Price of one hundred cubic feet at bed	Remarks
								Rs.	
Pathánkot, ...	Calcareous, without cavities and with slight contortions,	54	46	...	Scanty ...	Untried	...	...	To obtain fresh and well-burnt Batála kankar cement from contractors, it must be bought from them unslaked and unbroken. If the nodule can be broken with the hand without effort, it is well burnt and fresh. No powder from the kiln should be allowed. The cement should be carefully protected from the weather, and from the contact of air. If the Batála kankar is burnt unwashed, the cement obtained *may* be mixed with 40 per cent. by measure, of caustic lime; if washed, nothing but inert ingredients, like sand, washed kankar, &c., ought to be mixed with it.
Bhimpur (1), ...	(1) Compact, sandy and fossiliferous,	43	31	26	Do. ...	Conical field kiln, and with hot weather, of 2 of úpla to 1 of kankar.	Does not slake; gets hard again if not pounded immediately after burning...	24	
Bhimpur (2), ...	Like the Pathánkot nodule,	53	47	...	Do. ...				
Jandhy Chouty, near Togyál bridge,	Flat and hard stratified nodule,	51	49	...	Almost exhausted by road-making.	Conical kiln: 3 of úpla to 1 of kankar.	Ditto	28	
Near Sirkián bridge,	Like the Pathánkot nodule,	53	47	...	Do.	Conical kiln, in hot season 2 of úpla to 1 of kankar	Ditto	24	
Batála, ...	Extremely contorted nodule, full of cavities, filled with clay,	(if washed) 68·2	31·8	...	A large stock, but a great demand for roads.	Ditto	Ditto	11 (if burnt unwashed)	
Vahn, ...	Small contorted nodule, ...	72·1	27·8	...	x				
		Analyses taken from the Roorkee Treatise							
Ghazipur kankar, ...	x	72	28	...	These analyses are given in full in the Roorkee Treatise; but, as the amounts of carbonate of lime, of combined clay and of uncombined sand are the only components really interesting to the engineer, we have combined together the various elements of the given analyses so as they may be easily compared to ours.				
Lucknow No. 1, ...	"	72·3	27·7	...					
" " 2, ...	"	70·2	28·9	...					
" " 3, ...	"	67·7	33·3	...					

TABLE II.

Names of Localities	Analyses: Carbonate of lime	Analyses: Combined clay	Names of Localities	Analyses: Carbonate of lime	Analyses: Combined clay
Theil limestone (used for the Suez Canal), ...	81·91	18·09	Boulogne cement (natural), ...	65·15	34·85
Lias lime-tone (Lyme Regis),...	79·20	20·80	Vassy cement (natural), ...	63·80	36·20
Blue lias (Holywell), ...	71·55	28 48	Portland cement (artificial),...	62·00	38·00
			German cement (artificial), ...	59·08	40·92

TABLE III.

Components	Type of slightly hydraulic lime	Type of ordinary hydraulic lime	Type of eminently hydraulic lime	Type of limit lime	Type of cements inferior limit	Type of ordinary cement	Type of cements superior limit	Type of the beginning of puzzolanas	Remarks
Unburnt.									
Carbonate of lime	89	83	80	77	73	64	39	16·4	
Clay, ...	11	17	20	23	27	36	61	83 6	
Burnt.									
Caustic lime, ...	100	100	100	100	100	100	100	100	
Combined clay,...	22	36	44	53	65	100	100	900*	* Not combined.

TABLE IV.

Showing Results of Experiments made on Batála Kankar Cement burnt unwashed, Stone lime and Bricks.

Numbers	Composition of Specimens	Age in days at first trial	Crushing weight per square inch at first trial, dry specimens	Age in months at second trial	Crushing weights per square inch at second trial: Dry specimens: Maximum	Crushing weights per square inch at second trial: Dry specimens: Minimum	Crushing weights per square inch at second trial: Wet specimens	Percentage of absorption of water
			lbs.		lbs.	lbs.	lbs.	
I	Unrammed kankar cement, ...	28	860	$6\frac{1}{2}$	1,488	...	...	9 per cent. of weight.
II	Rammed " "	34	1,520	...	2,794	2,008	1,386	$5\frac{1}{3}$ " "
III	Rammed 1 kankar cement 2 washed kankar,...	37	2,163	...	2,487	1,936	1,564	4 " "
IV	Rammed 1 kankar cement 2 split boulders, ...	38	2,057	...	2,072	1,696	2,224	4 " "
V	Rammed 2 kankar cement 3 river sand, ...	33	1,489	...	1,360	1,132	1,030	6 " "
VI	Rammed 2 kankar cement 3 river sand mixture ground in a mill,	38	1,070	...	2,222	1,608	2,040	7 one-fifth ditto.
VII	Rammed $\frac{2}{15}$ kankar cement, $\frac{3}{15}$ sand, $\frac{10}{15}$ split boulders, ...	38	1,007	...	1,685	1,058	1,268	6 per cent. of weight.
VIII	Rammed 1 kankar cement 2 broken bricks,...	40	1,297	...	1,511	...	1,144	$11\frac{1}{3}$ " "
IX	Rammed 1 stone lime 2 brick súrki, ...	38	1,132	...	1,572	...	1,105	$10\frac{1}{3}$ " "
X	Bricks, ...	...	...	...	1,065	...	860	$14\frac{1}{6}$ " "

Report D, dated 29th November, 1873.

This report describes the practical results of all my experiments. The report will be divided in three parts, as follows:—*1st*, natural cements; *2nd*, artificial cements; *3rd*, concrete.

Natural Cements.—The works on the Bári Doáb Canal as far as Aliwál have, I believe, been constructed with stone burnt on the banks of the Chakki torrent. This stone or boulder lime, if honestly manufactured, is a hydraulic lime of fair quality, the strength of which is manifested by the solidity of the boulder masonry built with it. But if this lime is hydraulic enough to have been used on the canal works and on the Mádhopur weir, when it had plenty of time for setting and hardening, it was found to be insufficiently hydraulic when used on such works as the yearly repairs done to the rapids and falls. However, as Portland cement was too expensive, and the existence of natural cements was not an established fact, stone lime was still in use for those repairs when I joined the canal in 1870. Having found that the Batála kankar yielded a cement of very quick-setting properties, I asked permission to superintend the repairs of the rapids in January 1871, and to try this cement on them. Having found it to answer, I asked again permission to superintend the repairs in 1872, and to employ the cement more extensively. In January 1873, when I visited the rapids in company of the Supdg. Engineer and the Exec. Engineer, 1st Division, the repairs made with kankar cement were found in perfect order, even the chosen space in the centre of rapid No. 10, where the interstices between the boulders had been filled with concrete 24 hours before the re-opening of the canal, was in a very good condition. As no trace of the repairs done periodically with stone lime was to be found, the result obtained with cement was remarkable.

In January 1873, I did not superintend the repairs; some kankar cement prepared hastily was used, but the majority of the repairs were carried out with stone lime; thus it will be a matter of importance to ascertain when the canal is dry again in January 1874, if the repairs of 1873 have stood, and if their state warrants the further use of stone lime on such works; also if the repairs done with cement in 1872 have continued to stand well. If the question is decided in favour of kankar cement, as I have no doubt it will be, the first practical result of my experiments will be the introduction of a natural cement, the use of which will make the repairs of the rapids more durable, and will consequently diminish the number and duration of closures, so expensive and so injurious to the interests of the canal.

As a proof of the good results obtained with the cement at Mádhopur, I have only to state that I am indented on for cement whenever such a material is required.

As Batála cement, which has to be carried all the way from Raniah Dháriwál, where it is made, to the head of the canal, costs half as much again as stone lime, this being one of the greatest objections against it, the qualities of the kankars nearer Mádhopur were studied and tried. The Pathánkot block kankar was found to yield an eminently hydraulic lime of first-rate setting and cementing qualities, and several hundred feet of it were burnt and used on the Mádhopur weir and on the rapids. However, the digging for this kankar being deep, and the fuel expensive, the burnt kankar was found to cost a little less only than the Batála cement. The 1st Division is now, I believe, burning the Pathánkot kankar for the repairs, and is trying to reduce the former cost to a minimum. The calcareous deposits in the slopes looking towards the valley of the Beas from Bhímpur to the Kahnowán bund were found to produce cements and eminently hydraulic limes, but they are so much intermixed with calcareous sand stones containing too much silica in the state of sand, and flat kankars containing too much dissolved silica, that thorough discrimination is difficult, and the cements obtained generally poor. However, the Officers of the 1st Division are now endeavouring to take advantage of these deposits. I can therefore claim, as one of the results of my experiments, the opening of new sources of cementing materials, which materials were formerly believed to be very inferior.

Again, to reduce the expensiveness of mortar made with cement, the mixture of this material with sand was experimented upon, and employed to carry out extensive repairs at the bottom of the upper cistern of cascade No. 13. This experiment was made under great disadvantages, as, being short of time and of cement, this material was very roughly ground, and its mixture with unsifted stone lime and rough sand produced a mortar of slow-setting properties. Besides, the toe of the repaired wall, having no foundation below the surface of the flooring, was unprotected. When the work was examined in January 1873, it was found that about one-quarter of it had been carried away by the incessant grinding of pebbles and sand which takes place at the bottom of the cistern. This would look discouraging if the case was to be judged superficially; but when the disadvantages under which the mortar was made are thought of, when it is known that no good pointing was used to protect the mortar whilst setting, it will be admitted that the experiment is not conclusive either way, and ought to be repeated. As I have used sand successfully for concrete, I have no doubt myself that it can be used for mortar with safety.

Artificial Cement.—The experiments on this cement have gone through their first stage. The paste prepared by the dry process, and burnt in a flame kiln was found to produce a cement too slow-setting for practical purposes, and which is not likely to attain the high degree of induration of Portland cement. The cause of this weakness is, that the kankar used for the paste having been ground unwashed, the quantity of carbonate of lime in the sample was too small.

The sample now being prepared has been made with washed kankar, and a rough analysis shows it to contain about 63 per cent. of carbonate of lime. A small specimen burnt in a crucible has shown a high degree of hydraulicity. This sample ought, therefore, to give very good results. If it answers my expectation, and shows a strength nearly equal to that of Portland cement, I shall, if permitted to do so, submit plans and estimates for a cement factory moved by water-power and situated in a convenient site.

Concrete.—My experiments on small blocks have been described in the report of the 17th October, 1872. The results obtained show that the strength of Batála cement is equal to that of Roman cement, and that sand can be used with it in the proportion of 1 to 1 or even 2 to 3. The most important results, however, are those which show that if bad sand, even when full of mica slates, is ground with the cement, it produces a slow-setting powder whose ultimate induration in water is almost equal to that of neat cement. As many kankars yield cements and hydraulic limes superior in strength to that of Batála, and which can stand a much greater proportion of sand to cement than 2 to 3, their use, ground with the bad sands of the Punjab, is worth a trial, as such a fine powder would combine cheapness with the fine qualities required for concrete and mortar paste.

The experiments on large blocks commenced in January 1871, when I placed two blocks 2′ × 2′ × 1′ in the weir of No. 1 rapid. These blocks had been allowed four days' setting only before being laid in the weir; a week after the canal water was running over them. They stood very well, although the great flood of July 1871, and a mass of timber had passed over them, so, the canal being dry after the flood, 80 blocks, 2′ × 1′ × 1′, made in April and May 1870, were laid in the last third of rapid No. 10. These were visited in the beginning of the years 1872 and 1873, and were found to have stood very well, although some show signs of inferior manufacture. It was, I think, concluded from this experiment that such blocks would do very well for the floorings of the new falls.

The concrete-block machine designed with the view to ram the blocks with greater rapidity, to impart to them a higher and more equable specific gravity, is now in progress at the Mádhopur Workshops.

Note by Captain R. H. Palmer, S.C., *dated 18th December*, 1873.

Mr. Nielly has been most careful and industrious in ascertaining the various qualities of the kankar nodule in his neighbourhood, and in determining the best method of burning and preparing hydraulic lime thence obtained. The lime is undoubtedly excellent, and its good effects are visible on the works where it has been used, notably, where I have seen it myself on the Mádhopur weir, where it has stood the eroding effect of the river, where the other mortar (composed of stone lime and súrki) has been scoured out. The great cost of this lime prevents its being brought into more general use, and it is hoped that before long, further experiments will lead to a more economical proportion of the material; great credit is, however, due to Mr. Nielly for his labours.

As regards the concrete blocks, the rate per 100 cubic feet is very high, being equal to fine brickwork; at the same time the blocks prepared by Mr. Nielly are much finer in their texture than is required for the purposes for which they would be employed on the canal, being prepared, as Mr. Nielly describes, more on the Coignet system; the blocks are more adapted for cornices and mouldings than for the floorings of falls and bridges, it is probable that blocks suitable for this description of work could be made for about half the cost of those under reference.

Report E, dated 29th December, 1873.

Cost of Natural Cements.—The cost of lime or cement is a quantity so susceptible of variation, according to the density of the raw material, its abundance in the soil, the temperature, the cost of fuel, the distance the material, either raw or burnt, has to be carried, that it is difficult to give an accurate and constant rate even for one single place. However, I will endeavour to give an estimate, as close as possible to the truth, of Batála natural cement during the hot weather. Then the difference which the cold weather and the carriage to site of work will be taken in account, and rates for different places struck out.

Detail of Rates.

		RS.	A.	P.
Excavation of 100 cubic feet raw kankar about 3 feet deep,	=	1	12	0
Supervision per " " " ...	=	0	4	0
Rent of land " " " ...		0	3	0
Total cost of 100 cubic feet raw kankar, ...		2	3	0
Cost of fuel (úpla) per 100 cubic feet, ...		2	0	0
Making up the kiln, per 100 cubic feet raw kankar, ...		1	6	0
Picking up the cement, per 100 cubic feet cement, ...		2	7	0
Best hand-pounding of the cement, per 100 cubic feet cement, ...		4	0	0

From the above rates we may deduce the cost of 100 cubic feet natural cement in the following way, not neglecting the facts that nearly 150 cubic feet of raw kankar are required to produce about 100 cubic feet of cement, and that in the hot season 2 by measure of fuel to 1 of raw kankar is the proper proportion, whereas in the cold weather 2·5 of fuel to 1 of raw kankar is the proportion. Should the kankar be washed before burning, from 3 to 3·5 of fuel would become necessary.

Calculation of the cost of 100 *cubic feet, Natural Cement at Batála.*

		RS.	A.	P.
150 cubic feet raw kankar, at Rs. 2-3 per 100 cubic feet, ...	=	3	4	6
300 cubic feet úpla, at Rs. 2 per 100 cubic feet, ...	=	6	0	0
Making up the kiln, per 100 cubic feet raw kankar, ...	=	2	1	0
Picking up the cement, per 100 cubic feet cement, ...	=	2	7	0
Best hand-pounding of the cement, ...		4	0	0
Cost of 100 cubic feet natural cement, total, ...		17	12	6

Adding to this rate the increment for one-fourth more fuel during the winter, and the cost of carriage at 8 annas for short distances and 6 annas for the longest, we get the following rates for the different sites of work along the canal :—

Rates of Natural Cement.

Names.	Rates during hot season.	Rates during cold season.
	RS.	RS.
Aliwál, ...	19·781	21·281
Kila Lál Singh, ...	20·281	21·781
Kunjar, ...	22·281	23·781
Kallair, ...	25·781	27·281
Rania, ...	23·781	25·281
Talwandi, ...	25·781	27·281
Bábiali, ...	26·781	28·281
Tibri, ...	27·781	29·281
Mádhopur, ...	35·781	37·281

These rates might be reduced by grinding the cement in native mills. The best way to do this cheaply and conveniently would be to obtain from the 1st Division, and build as near the canal falls as possible, kacha mills which could after completion of our works be let out to native millers. If we pay for these mills a water-rate of 4 annas per day and per pair of stones, and if we assume that each pair will grind 50 cubic feet per day with the attendance of two millers at 4 annas each, the grinding will cost Re. 1-8 per 100 cubic feet; add to this Re. 1 for roughly breaking the cement before giving it to the mills, and the total cost of grinding will be Rs. 2-8 instead of Rs. 4. By using mills, we shall, therefore, gain by two ways—1*st*, in greatly lowering the rate; 2*nd*, in reducing the cement to very fine powder, which is an advantage of no mean value.

Rates of Artificial Cements at Rania.

		RS.
200 cubic feet raw kankar (to produce 100 cubic feet cement), at Rs. 7·437 per 100 cubic feet, ...	=	14·875
Washing 200 cubic feet kankar, at Re. 1 per 100 cubic feet,		2·000
Grinding and sifting, at Rs. 50 per 100 cubic feet raw kankar, ...		100·000
Making the ground kankar into cakes, at Rs. 3 per 100 cubic feet ground stuff, ...		4·000
50 maunds wood, ...		12·500
Labour of burning 100 cubic feet cement, ...		5·000
Carried over, ...		138·375

	RS.
Brought forward, ..	138·375
Grinding and sifting the cement, at Rs. 100 per 100 cubic feet, ...	100·000
Cost of 100 cubic feet artificial cement worked by hand, total, ...	238 375

The cost of one cubic foot would then be Rs. 2·383.

These rates might be easily reduced by choosing a convenient site for a factory capable of producing 100 cubic feet per day, and by employing native mills as a grinding and moving power. If, for instance, we choose Aliwál, in the vicinity of which there is abundance of kankar, and where plenty of water-power may be obtained, where, besides, large buildings are available, the rate would become as follows:—

Details of Rate.

	RS.
200 cubic feet raw kankar, at Rs. 3·562 per 100 cubic feet,	7·124
Washing the above, at Re. 1 per 100 cubic feet, ...	2·000
Grinding and sifting by water-power, at Rs. 5 per 100 cubic feet, ...	10·000
Making the ground kankar into cakes, at Rs. 3 per 100 cubic feet ground kankar, ...	4·000
50 maunds wood, ...	12·500
Labour of burning, ...	5·000
Grinding and sifting the cement, ...	10·000
Cost of making 100 cubic feet artificial cement, total,	

or eight annas per cubic foot of 89 lbs., or 112 lbs. per bushel. It would be premature to compare this rate with the rate in England for Portland cement, because the strength of the sample of artificial cement just manufactured has not yet been tried. This sample is good as far as hydraulicity goes, but its strength cannot be known before the beginning of January 1874.

Cost of Concrete made with Natural Cement.—When concrete is well rammed, 160 cubic feet of materials are required to make 100 cubic feet of concrete. The proportion of mixture being one of cement to 3 of raw kankar, 40 cubic feet of cement and 120 cubic feet of kankar will be required per each 100 cubic feet of concrete; then the cost of 100 cubic feet raw kankar being as given in column 2; the cost of concrete blocks per 100 cubic feet at various places along the canal will be as entered in column 6.

Names of Places.	Cost of kankar per 100 cubic feet	Cost of labor and mould at 3 annas per cubic foot.	Cost of 120 cubic feet kankar.	Cost of 40 cubic feet cement.	Cost of concrete blocks per 100 cubic feet.
	From Batála.				
	RS.	RS.	RS.	RS.	RS.
Aliwál, ...	3·562	18·75	4·274	7·900	30·924
Kila Lal Singh, ...	4 375	18·75	5·250	8·100	32·100
Kunjar, ...	6·125	18·75	7·350	8·900	35·000
Kallair, ...	7 875	18·75	9·450	10·300	38·500
Rania, ...	7·437	18 75	8·924	9·300	36·974
Talwandi, ...	8·750	18·75	10·500	10·300	39·550
	From Beas slopes.				
Babáili, ...	7·500	18·75	9·000	10·700	38·450
Tibri, ...	6·500	18·75	7·800	11·100	37·650

The above rates will be considered high; what makes them so is especially the cost of carriage, and also that of labour—expenses little susceptible of reduction. The cost of labour is that of blocks made on the Coignet system, and if it was reduced, it would be at the expense of the homogeneity and durability of the blocks. The concrete block-machine is expected to effect a saving, but it has yet to be proved by experiments.

Report F, dated 18th April, 1875.

Plain chemical composition of Kankars, &c.—The Appendix F[3] contains a list of analyses made by Mohr's process; most of them were checked by Lieut. S. Jacob, R.E. The Siálkot kankars were analyzed with a view to their being useful on projected canals in the Rechna Doáb.

The main results from these analyses are—

1st.—That there is in the Hoshiárpur District a honey-comb, shelly tufa deposit as rich in carbonate of lime as many of the chalks, and which could, therefore, be used for the manufacture of Portland cement. The deposit is reported to be extensive, and it does not seem to be a solitary one in Upper India, as the Roorkee Treatise speaks of a similarly rich deposit at Behmurri, in the Gorakhpur District, North-Western Provinces.

2nd.—That the Vahn kankar and similar ones might be used for artificial cement without the admixture of clay; but their most excellent qualities as natural cements would preclude the incurring of an extra expenditure for making them artificial.

3rd.—That all the ordinary kankars are not sufficiently rich in carbonate of lime for the manufacture of artificial cement.

4th.—That the majority of nodular kankars contain when washed from 49 to 54·5 per cent. of carbonate of lime, but when not washed from 32 to 39 per cent. As the tenacity of burnt kankars must be greatly diminished by leaving them unwashed, the worst kinds especially ought to be washed if great tenacity is a desirable object.

Neat Cement.

Experiments on Tenacity.—Batála kankar, one month old, mean, ...	61 lbs.	per square inch.
Batála kankar, six months old, mean, ...	75 „	„ „
„ „ twelve „ „ „	82 „	„ „
Patháukot kankar, four months old, mean, ...	27 „	„ „

Artificial Cement.

Made with Batála kankar, one year old, ...	51 „	„ „
Half artificial, half natural, „ „	93 „	„ „
Tenacity of Concrete.—Béton made with Batála kankar burnt with wood and raw kankar in the proportion of 2 to 3, two months and twenty days old, ...	106 „	„ „
The same, the kankar burnt with úpla, ...	67 „	„ „
Béton made with kankar sent for trial by E. C. Palmer, Esq., two and a half months old,...	131 „	„ „

The tenacity of the Batála cement is scarcely one-tenth of Portland; Batála can only be classed among the weak Roman cements. Weak as it is, it is, however, greatly superior to Patháukot stuff, whose weakness takes one by surprise, as its strength under compression is great. It must be remarked that the Patháukot is reddish before and after burning, and this, it is thought, is a general sign of weaknes, the dark grey colour of the clay which surrounds the kankar being, on the contrary, a sign of strength.

The tenacity of concretes is very instructive, as it shows itself to be much greater than the tenacity of neat cement. Mr. Palmer's kankar especially is remarkably strong, as one of the specimens required the great weight of 168 lbs. per square inch to break it. This is almost equal to Portland cement and sand in the proportion of 1 to 2.

The difference in tensile strength made by the difference in the fuel used is also very instructive, and points to the conclusion that, if confirmed by further experiments, úpla ought to be rejected for fuel.

Notes on Artificial Cements made with Kankars.—The artificial cement made obtained a tenacity of only 51 lbs. per square inch after one year.

The cause of this weakness is the deficiency of carbonate of lime in the kankar as shown in Appendix E².

The main result of the experiments is not, therefore, the production of a good artificial cement, but the proof of the practicability of overburning the artificial cements with a flame kiln composed of one circular shaft connected with one pair or more of opposite furnaces fed with wood, the flames of which converge in the axis of the shaft.

It was found that the plainest method of making cement nodules or cakes was to manufacture them by hand into small buns about 2½ inches in diameter and half an inch in thickness.

Notes on Concrete.—For each 100 cubic feet of concrete 200 cubic feet of kankar are required. The smaller the kankar is the better. If small stuff is not procurable, the kankar ought to be passed through a screen with intervals of ¾-inch between the wires; the larger pieces are used for burning; the smaller are washed and used for the concrete.

The kankar burnt with úpla sets faster, and is much more unctuous (*chikna*, the natives would say) than the kankar burnt with wood. For burning with wood, the native circular clamp as used for burning boulder lime stone will answer. The experiments on tenacity show that the cement burnt with úpla has only ⅔rds of the strength of the cement burnt with wood. This fact will be tried again for confirmation.

To manufacture the blocks, the kankar well washed is mixed in its wet state with the cement; then a quantity of water, varying from 25 per cent. of the weight of the cement during wet days and during the winter, to 35 per cent. during the hot dry heat of the summer,* is slowly added to the mixture. This mixture ought to be briskly and methodically shovelled whilst the water is dropped on it. The stuff so prepared, in small quantites, on account of the fast-setting qualities of kankar cement, is carried to the moulds and rammed in layers of about 3 or 4 inches, each layer, when complete, being thoroughly scraped to ensure its getting well joined to the next layer. When the block is finished, the mould is taken out without difficulty, and the block gently upset on a layer of sand. The rammers are rectangular in form, and weigh eight seers.

The grinding of the sand full of mica with the cement gives good results for superstructure, and for mortar under still-water, when the cement used is not very stong, as the Batála; but it gives good results under water in any position if used in connexion with a very good cement, like that of Vahn. It would be advisable, therefore, to employ it but only when great facilities for grinding in a mill are at hand, and when it really effects a saving in the cost of mortar and concrete.

* *Vide* remarks upon these quantities of water in undersigned's paper on Mr. King's experiments.

APPENDIX F².

Analyses of Kankars, Tufas, &c., by Mohr's process.

Numbers	Names of places where the kankars are found	State of external purity	Percentage of carbonate of lime	Percentage of impurities (clay, iron, &c.)	Remarks
1	Tufa full of shells, found in the Hoshiárpur District, ...	No washing required	88·00	12·00	Excellent for Portland cement
2	Patháukot tufa, ...	Washed	49·00	51·00	
3	Bhimpur sandy nodule, ...	No washing required	34·25	65·75	
4	„ compact,...	„ „	From 50 to 59·25	From 50 to 40·75	
5	„ small nodule, the sweeping of the slopes, ...	„ „	75·00	25·00	
6	Jandhy Chouty flat kankar, ...	„ „	52·50	47·50	
7	Kaligpur ordinary nodule, ...	Washed	54·75	45·25	
8	Kalánaur „ „ ...	Unwashed	32·50	67 50	
9	Virka, „ „ ...	Washed	47·00	53 00	
10	Tong, „ „ ...	„	52·00	48 00	
11	Jaitha on Kirn escape, ...	„	52·50	47·50	
12	Kankar on Aliwál escape, ...	„	54·25	45·75	
13	Batála ordinary nodule, ...	„	54·50	45·50	
14	„ „ „	Unwashed	38·75	61·25	
15	„ inferior, ...	... ...	28·75	71 25	
16	Kankar on Mooltan branch, four miles below Aliwál, ...	Cleaned by rain only	41 50	58·50	
17	Kankar on Batála road, nine miles from Amritsar,...	Washed	52·50	47·50	
18	Vahn kankar, ordinary nodule,...	No washing required	57·50	42·50	Good for Portland cement without admixture of clay.
19	Vahn kankar, small nodule, ...	No washing required	67·75	32·25	Ditto ditto
20	Bhoman Vadála rocky kankar, ...	„ „	51·25	48·75	
21	„ „ nodule, ...	„ „	49·00	51·00	
22	Kankar near Lahore, ...	„ „	47·50	52·50	
23	Sample sent by E.C. Palmer, Esq.,	Washed	50·00	50·00	
24	„ „ „	Unwashed	39 15	60·85	
	Kankars from the Sialkot District				
25	Akrota rocky kankar, ...	Washed	53·00	47·00	
26	„ „ „	Unwashed	48 25	51·75	
27	Sudha „ „	Washed	53 50	46·50	
28	„ „ „	Unwashed	50·00	50 00	
29	Lodhra nodular, ...	Washed	58·25	41·75	
30	„ „	Unwashed	48·50	51·50	
31	Jhummal nodular, ...	Washed	53 50	46·50	
32	„ „	Unwashed	44·25	55·75	
33	Pipliwála, nodular, ...	Washed	42·00	58·00	
34	„ „	Unwashed	36·75	63·25	
35	Gukhka metur, ...	Washed	42·75	57·25	
36	„ „	Unwashed	33·25	66·75	
37	Kokamird metur, ...	Washed	43·00	57·00	
38	„ „	Unwashed	36 25	63 75	
39	Chickwaty „	Washed	43·00	57·00	
40	„ „	Unwashed	33 50	66·50	
41	Godpur rocky kankar, ...	Washed	52·25	47·75	
42	„ „ „	Unwashed	48 00	52·00	
43	Parály nodular, ...	Washed	44·00	56·00	
44	„ „	Unwashed	38·75	61·25	
45	Kobah Chack rocky, ...	Washed	47·25	52 75	
46	„ „ „	Unwashed	44 50	55·50	
47	Ballanwálah „	Washed	50 50	49·50	
48	„ „	Unwashed	46 50	53·50	
49	Sahowálah „	Washed	57 25	42·75	
50	„ „	Unwashed	56·50	43·50	
51	Wazirabad nodular, ...	Washed	43·85	56·15	
52	„ „	Unwashed	32·00	68·00	

Report G, dated 10th April, 1875.

Remarks on some details of the Experiments made by M. King, Esq., *Assist Engineer.*

It is stated by Mr. King that various clays would be mixed with the hydrate of lime: as it has been inferred from past experiments that the blue river clay was necessary for the manufacture of artificial cement, it would be useful if Mr. King stated which kinds of clays he used answered best, and what were their components. The attempts at artificial cement, made here with the kankar reduced to powder, and treated by the German process, failed to produce a strong cement.

The needful degree of heat may be obtained without bellows and with wood for fuel, by using a flame-kiln composed of one circular shaft containing the stuff, heated up by two opposite furnaces, whose flames would converge in the axis of the shaft.

An easier way of making test-bricks is obtained by employing iron-moulds in two pieces, and by using the following process of making béton. The process consists, instead of reducing the natural cement, or the ordinary mixture of lime and súrki, to the consistency of a paste, in mixing with such cement or such mixture a weight of water equal to from 0·25 to 0·35 per cent. of its weight, the greatest proportion being used when the atmosphere is the hottest and most dry. With overburnt artificial cement like Portland, the proportion of water is much smaller (*vide* Gillmore, para. 92).

The effect of this minimum quantity of water, which leaves the stuff in an apparently incoherent state, is that—

1st. The ramming is done without any difficulty, no quicksand motion taking place.

2nd. No adhesion occurs between the bricks and the sides of the mould, which mould can be removed at once and used for making more bricks.

3rd. The bricks can be gently handled and placed in water 24 hours after manufacture. Putting the bricks in water, or wetting them, immediately, or too soon after manufacture, is injurious.

The mould ought to rest on a small flat piece of wood or platform placed on a few inches of sand to check the vibration caused by ramming. After removal of the mould, the brick resting on its platform is put in a safe place. The test of bricks made by the above process gives the value of cement or lime for béton.

Almost all what is said before can be applied to the manufacture of blocks of any size, and the process described above has been proved to be remarkably suited to the manufacture of kankar béton. It was found, however, that if the cement or lime employed was not mixed naturally with a sufficient amount of clay, or artificially with a sufficient amount of súrki, or puzzolana, or sand, cracking would take place when immersion of the sample is made after the usual interval of 24 hours. Therefore, before using any stuff rich in carbonate of lime, it is advisable to make a few little blocks or bricks as described, and with the lime mixed with various proportions of súrki, or, for cheapness sake with good sand; then a mean between the proportions which would give the smaller amount of cracking and no cracking at all after immersion, would give very nearly the proper proportion of lime to súrki or sand.

The proportions of water given for béton are actually in use on an extensive manufacture of kankar blocks for the Bári Doáb Canal; these proportions give to the béton the greatest density, as being very nearly the amount required chemically for hydration; the porosity caused by the evaporation of the excess of water generally used and generally thought to be necessary is eliminated.

A. N.

II. Review of preceding Reports, by Thomas Higham, Esq., Exec. Engineer.

The value of any concrete depends so materially on the quality of the lime employed, that it will be convenient to consider this question first, and to note those parts of Mr. Nielly's reports that refer to the manufacture of lime.

The limes available in the 1st Division, Bári Doáb Canal, are the fat stone lime procurable from Mámún near Pathánkot, and kankar lime procurable from various kankar deposits between Pathánkot and Batála. The former makes an excellent mortar when mixed with good súrki, in the proportion of about 1 to 1·5, but does not set readily under water. I understand that kankar lime was employed freely during the construction of the canal, and that it was used exclusively in at least three rapids; but judging from the large stores of stone lime collected for the remodelling works, and the fact that it had until lately been almost universally used throughout the Division, it would appear to have grown out of favour before

Mr. Nielly's experiments were made. The reason of this, in the upper part of the Division, was probably the comparative cheapness of stone lime, and the very admirable mortar that it gives in composition with súrki when not required to set under water. Lower down the conditions of economy are reversed, and it is difficult to account for the scant degree in which it was employed, except on the supposition that careless burning and unscrupulous mixture of ashes and underburnt kankar had led to a prejudice against it. Such a prejudice must have been permanently removed by the excellent specimens obtained by Mr. Nielly from kankar lime, and he deserves great credit for the care that he has bestowed on the selection and burning of the kankar, and for the persistency with which he has preferred the use of kankar to that of stone lime. Attention is drawn to the satisfactory result given by the use of kankar lime in the repairs of rapid No. 10, alluded to in Report D, in a position where stone lime had constantly failed.

Mr. Nielly applies the name of *cement* to the kankar lime thus obtained. In support of the term, he adduces the authority of Vicat as covering the application of the word to all limestones in which the percentage of carbonate of lime varies from 73 to 39 per cent.—*see* Table III., Report C. This is a wide range, and certainly none of the limes hitherto obtained can be called cements in the sense in which the word is used by English Engineers. Rankine gives the percentage of carbonate of lime in a natural cement at 41, and adds the practical test that it must harden under water, so as to resist the pressure of the finger, in a few minutes. As will be shown further on, the lime obtained does not fulfil this test, and it seems to me a misleading term to apply to materials that bear no resemblance, either *in point of tenacity* or rapidity of setting, to what is generally understood in England by the word cement. It is an eminently hydraulic lime, but not a cement; and it will be, I think, convenient to drop the use of the latter word.

In regard to the process of burning with úpla, Mr. Nielly states, in Report B, that a kiln burnt with úpla and kankar, in the proportion of 2 to 1, resulted in an out-turn of 50 per cent. underburnt lime; but that when he raised the proportion of úpla to three times the bulk of kankar, the underburnt portion was only 5 per cent. of the whole. In Report E, he states that 2 cubic feet úpla to 1 of raw kankar suffice in the hot weather; but that this should be raised to 2½ cubic feet in the cold weather. In the

2nd Division, where kankar lime is universally employed, the usual proportions are 3 to 1, and as a general rule not less than 2½ should be employed, though of course the quantity must vary slightly with the composition of the kankar employed. With washed kankar Mr. Nielly gives 3 to 3½ as the proper proportion.

In the same Report E, it is stated that 150 cubic feet raw kankar are required to produce 100 cubic feet lime. The result of manufacture on a considerable scale at Kila Lál Singh, to be referred to afterwards, shows that nearly 160 cubic feet were used for every 100 feet of lime burnt.

The careful unloading of the kiln is a matter of great importance. Mr. Nielly has the pieces of burnt kankar picked out by hand, and all underburnt pieces, ashes and fine stuff most carefully separated. The process is rather laborious, but very necessary, and neglect of it is no doubt the main cause of the inferior and worthless limes so frequently met with.

The grinding of the lime is effected either by hand or by bullocks working an edge stone. The machine would be too expensive except for use in large works. A small grinding drum that could be worked by coolies is now being made up at Mádhopur, and will probably be an improvement on the hand-pounding process.

It is desirable that the raw kankar should be washed before burning. Where this is not done, the clay adhering to the kankar nodules is calcined in the kiln into súrki. In kankars containing over 50 per cent. carbonate of lime, this súrki will not be very injurious, and it would perhaps be preferable to leave the kankar unwashed on account of the expense attending the washing process. The labour of washing would amount to about Re. 1 per 100 cubic feet of kankar, or Re. 1-8 per 100 cubic feet of lime; but in addition to this, there is the loss of material incurred by washing, which may be taken at 17 per cent. Thus, when the kankar is washed, nearly 200 cubic feet raw kankar will be required for 100 cubic feet lime, whereas 150 or 160 would suffice without washing. In kankars that are very poor in carbonate of lime, washing would be desirable, or a small portion of white lime might be added to the lime obtained without washing. With the generality of kankar, however, the addition of white lime causes little or no improvement in the quality, (*see* Report B.)

I now come to the properties of the lime thus obtained. On the important point of hydraulicity, or rapidity of setting under water, Mr. Nielly remarks in Report B, that the Batála kankar lime, finely pounded, made into a thick paste, and thrown into water immediatly after being made up into a ball, hardens so as to resist the penetration of a fine needle after a fortnight, and that if it is allowed 20 hours' setting before being placed in water, it will after the 20 hours, if placed in water, resist the penetration of the fine needle. Such a lime is excellent for hydraulic purposes, but, as above remarked, cannot be called a cement.

Table IV. with Report C, gives the crushing weights per square inch for a variety of specimens of kankar lime by itself and in combination with sand, kankar, broken bricks, or boulders, &c. A plain block of kankar lime unrammed was crushed with a weight of 860 lbs. after 38 days, but a specimen kept for 6 months broke under a weight of 1,488 lbs. per square inch. Rammed specimens give much higher results, but the table will speak for itself. The column showing percentage of absorption of various specimens is interesting and useful: this percentage varies from 4 to 11.

For making concrete, and indeed for all canal work, where the mortar has to resist the wear and tear of running or falling water, rather than dead weight of some heavy superincumbent structure, the tensile strength of the specimens is of more importance than the resistance to crushing. The tenacity of Batála and Pathánkot kankar lime has been only recently the subject of experiment. The results are given in Report F.

It will be seen that Batála kankar one month old, has a mean tensile resistance of 61 lbs. per square inch, and that this increases to 82 lbs. when the specimens are 12 months old. The Pathánkot kankar lime has a resistance of only 27 lbs. after 4 months. Portland cement has a tenacity of from 300 to 350 lbs. per square inch after 7 days, and even Roman cement (with which Mr. Nielly compares the Batála lime) should have a tenacity of 90 lbs. when 7 days old. No specimens have been tried under a month old, but they would probably give a tenacity much under 61 lbs., the result obtained with specimens of that age. On the ground of low tenacity, therefore, as well as slowness of setting in water, the use of the word "cement" as applied to this lime is misleading and inconvenient.

In regard to the cost of manufacture, the figures given in Report B, and in Report E, may be passed over. The rates given are to a certain extent conjectural, and are based at least upon a limited experience. The manufacture of concrete blocks has been recently commenced on a larger scale, and the following are the details of expenditure incurred in burning nearly 3,000 cubic feet of lime:—

		RS.	A.	P.				RS.	A.	P.
4,504 cubic feet raw kankar,	@	5	12	0	per 100 c. ft.		=	258	15	8
Loading kiln (4,504 cubic feet kankar),	@	1	3	1	"	"	=	53	13	3
11,107 cubic feet úpla,	@	1	12	0	"	"	=	194	5	11
Unloading kiln (2831·5 cubic feet cement),		1	8	0	"	"	=	42	8	9
Grinding 2831·5 cubic feet,	@	1	8	10	"	"	=	43	14	6
								593	10	1
To this may be added, on account of mistri, mates, and other general charges—Contingencies at 5 per cent, ...								30	0	0
Total cost of 2831·5 cubic feet lime,							=	623	10	1

equivalent to a rate of Rs. 22 per 100 cubic feet.

In the above the kankar is not washed. The cost of washing is a little less than Re. 1 per 100 cubic feet of raw kankar, and the bulk of the kankar would be reduced about 17 per cent. by the process, so that 5,427 cubic feet would be required, or 923 cubic feet more than when the kankar is unwashed. Three cubic feet úpla instead of $2\frac{1}{2}$ will also be required per cubic foot.

		RS.
The extra cost will, therefore, be $\frac{1}{5}$ more for úpla $= \frac{194 \cdot 38}{5}$	=	38·87
923 cubic feet raw kankar, at Rs. 5-12-0 per 100 c. ft., ...	=	53·07
5,427 cubic feet kankar washing, at Re. 1 " " ...	=	54·27
Total, ...		146·21

which would bring the total cost up to Rs. 770, or about Rs. 26-3-0 per 100 c. ft. lime.

Let a = rate for raw kankar per 100

b = " for úpla ;

then the following formula will give approximate cost of the lime per 100 c. ft.—

If the kankar be washed, cost $= 2a + 5b + 7$

" " unwashed " $= 1 \cdot 7a + 4 \cdot 2b + 5$

The method and cost of burning kankar by wood fuel has hardly been noticed by Mr. Nielly. It is, I think, generally more convenient and economical to employ úpla; but it will be seen from Report F, that concrete specimens made with lime burnt with wood had a far higher tenacity than when the lime was burnt with úpla, but the fact certainly requires confirmation.

In conclusion of this part of the subject, I would call attention to the analyses given in Reports C and F of different kankars. These analyses have been conducted by a very handy and expeditious process. A known weight of the specimen is pounded to powder, and treated with a solution of nitric acid until all the carbonic acid is expelled. The quantity of carbonate of lime in the specimen is found from the fact that one centimetre of acid combines with ·05 gramme of carbonate of lime. Any acid that may have been added in excess is neutralized by the addition of caustic potash, of such a strength that one volume of caustic potash will neutralize one volume of the acid. The quantity of caustic potash used (in centimetres) is then deducted from the quantity of acid used, and the balance shows the amount of acid that has combined with the lime, from which the proportion of carbonate of lime can be accurately ascertained. A specimen can be analysed in this way in about 10 minutes. The analysis of course shows only the proportion of carbonate of lime; but this is very useful in practice, as it will show whether the kankar will yield a mere puzzolana, that will require to be mixed with fat lime, or whether it will give a lime so rich as to require to be mixed with súrki. This can of course be determined by experiment after the lime is burnt, but an analysis of this sort is particularly useful in ascertaining the limits of variation in the composition of the kankar in any particular locality or bed. The apparatus required is excessively simple, and might with advantage be more extensively employed.

The manufacture of concrete may now be considered independently of the question of burning the lime. Report A is of little practical interest, as it was for the most part written before any extensive experience had been acquired. A statement is appended showing the composition of 17 different blocks, many of which had been placed under the falls and in the rapids, and found to stand well. In many of these blocks, stone lime was mixed with the kankar lime. The weight was about 136 lbs. per cubic foot.

Report B mentions two blocks made without mixture of stone lime, which were capable of being carried three or four days after they had been made, and which were found to weigh 143 and 145·5 lbs. per cubic foot. Concrete of this weight may be regarded as very superior.

The resistance of various specimens of concrete to crushing is given in Table IV.

Report C, Specimens III. and IV., represent the common type of concrete now manufactured, and give a resistance to crushing of upwards of 2,000 lbs. per square inch 38 days after manufacture. Split boulders as the principal material, appear to give a better result than raw kankar, in the case of wet specimens, though the result is reversed when the specimens are dry. The resistance obtained is more than double that given by a hard brick.

Very few experiments have been made on the tenacity of concrete specimens, the only information on this point being given in Report E.

When the lime was burnt with wood, a resistance of 106 lbs. per square inch was obtained after two months and 20 days; but when burnt with úpla only 67 lbs. per square inch. Another kankar used gave a resistance of 131 lbs. A fuller report will be subsequently made on this point, when proper apparatus has been made for testing specimens now awaiting trial.

A brief account of the method of manufacture is given in Report F by Mr. Nielly. The salient points are—

That the kankar should be broken into pieces that will pass through a ⅝-inch mesh, and well washed. It is a matter of primary importance that the kankar be washed free of all adhering clay; the object of breaking it up into small pieces is to facilitate the washing, as it is impossible by mere washing to remove the clay from a large irregularly shaped nodule.

Lime burnt with wood has given higher tensile resistance than when úpla-burnt lime has been used; but further experiments are necessary to establish this, and the úpla-burnt sets faster, and is, as a rule, cheaper.

An excessively small quantity of water is used, varying from 25 to 35 per cent. of the weight of the lime employed. The small quantity of water used is the distinguishing feature of the blocks made by Mr. Nielly, and the mixture is so dry, that at first sight it would seem impossible to secure cohesion; but the blocks are of excellent quality, and can be handled freely directly they are made.

Sand may be used, if ground up with the lime; but, with the ordinary kankar limes, this is not advisable for works under water.

The proportions of lime and raw kankar are not stated by Mr. Nielly in the note above referred to. In the blocks that are now being made up on a large scale for the remodelling works, the proportions observed are two measures of lime to three of raw kankar. This proportion gives excellent results; but, as I shall presently show, the quantity of lime used might probably be diminished with advantage.

In regard to cost, I have the details of all expenditure incurred in making up 4,000 cubic feet of concrete of above composition at Kila Lál Singh. The blocks were for the most part 2′ × 2′ × 1′, or 4 cubic feet each, though there were a few closers made half size, or 2′ × 1′ × 1′.

To make the above 4,000 cubic feet concrete, 8,496 cubic feet kankar were required.

Of this, 4,504 were burnt for lime, and 4,792 used as material for concrete.

The 4,504 cubic feet burnt yielded, ... 2831·5 cubic feet lime.
The 4,792 cubic feet raw kankar yielded, .. 3977·5 when washed.

Total bulk of materials rammed, .. = 6809·0 cubic feet, to give 4,000 cubic feet of concrete, so that for 100 cubic feet concrete, 170 cubic feet of materials are required.

Of this 170 cubic feet—

⅖, or 68 cubic feet, are lime, or say 70
⅗ „ 102 „ „ or raw washed kankar, or 100

But for 100 cubic feet of washed kankar, 120 cubic feet of raw kankar are required.
Washing the kankar costs ·9 rupee per 100 cubic feet unwashed.
Labour in mixing and ramming costs 4·3 rupees per 100 cubic feet of concrete.

When kankar for lime is burnt unwashed, the cost per 100 cubic feet will be—

When a = price of kankar per 100 cubic feet.
b = „ of úpla „ „ „
Cost per 100 cubic feet of lime = $1·7a + 4·2b + 5$.

Hence for concrete—

70 cubic feet lime = ·7 $(1·7a + 4·2b + 5)$	=	$1·19a + 2·94b + 3·50$
120 „ „ kankar = $1·2a$	=	$1·20a$
Washing = 1·2 × ·9	=	1·08
Labour in ramming and mixing, ...		4·30
Total, ..		$2·39a + 2·94b + 8·88$
Contingencies at 5 per cent., ..		$·12a + ·15b + ·44$
Total cost per 100 cubic feet concrete, ..		$2·51a + 3·09b + 9·32$

When the kankar for lime is washed before burning, the cost of lime per 100 is $2a + 5b + 7$, and the cost of concrete will be $2·73a + 3·71b + 10·92$.

At Kila Lál Singh, the price of kankar was 5·34 rupees per 100, and of úpla 1·75 per 100.

Hence price of lime with kankar unwashed before burning should be—

		RS.	AS.	P.	
1·7 + 5·34 + 4·2 + 1·75 + 5	=	21	6	10	per 100
The actual cost at this place was	=	21	10	9	„
And the price of concrete should be—					
2·51 + 5·34 + 3·09 × 1·75 + 9·32 ..	=	28	2	1	„
The actual cost being		28	2	11	„

The allowance for contingencies covers the expense of making moulds, repairing tools, &c.

The moulds are made of stout *kikar* planks, fastened together by iron bolts. The cost of each for the large blocks is Rs. 9, and for the small ones, Rs. 5.

The proportion of lime to kankar employed above appears to me to be more than is necessary.

Concrete blocks of excellent quantity have been made up in the 2nd Division with the proportion of lime to kankar as low as 1 to 3; and in point of hardness at least they were certainly in no way inferior to those made by Mr. Nielly, it being difficult to make any marked impression on them by subjecting them to several blows with the edge of a *phoura* or point of a pickaxe, after they had been made a few months. The blocks referred to in Report B were of very excellent quality, and, judging from their great density leave nothing to be desired: the proportions employed were 1 lime to 2 kankar. The bulk of materials employed to make four cubic feet was 5½ feet in one case, and 6⅔ in the other. The latter proportion would require only 160 cubic feet materials for 100 cubic feet concrete. With the block made at Kila Lál Singh, 170 cubic feet were used, and to be on the safe side, the proportion of 170 to 100 may be taken as the ratio of consolidation. The cost with lime to kankar as 1 to 2 would be, with kankar unwashed before burning—

$$2{\cdot}46a + 2{\cdot}52b + 8{\cdot}80$$

If the lime be washed before burning, it would be—

$$2{\cdot}64a + 3b + 9{\cdot}99.$$

The first of the above formulæ would give the cost at Kila Lál Singh rates at Rs. 26-5-5 per 100, or nearly Rs. 2 cheaper than when the proportion is 2 to 3.

But it is not on the mere score of economy that I would recommend the use of less lime. Until tension bricks are made up with concretes of various composition, it is difficult to say what proportion is best; but it would seem natural to suppose that, so long as the lime is sufficient to fill up all the interstices between the kankar nodules, the best stone, as well as the cheapest, is that in which the lime bears the smallest proportion to the kankar. The great density of blocks made by Mr. Nielly with proportions of 1 to 2 shows that there can be but little porosity, and that the lime used was sufficient.

Mr. Nielly states that the larger proportion of lime is necessary by his dry process to secure perfect diffusion, but that if more water were used, less lime would suffice, as the fluid mortar would more readily fill up all interstices. This brings to me a consideration of the dry process, which Mr. Nielly explains at length in his Note on Mr. King's experiments (Report G). The comparative ultimate strength of concretes made with different quantities of water has yet to be determined; but it seems to me that if it is a necessity of the dry process that the block should contain 40 per cent. of lime, it is a grave disadvantage, both on the score of cost and strength. In addition to the specimen blocks originally made by Mr. Palmer, blocks have been made up by hundreds in the 2nd Division with only 25 per cent. of lime, and that well slushed with water; and these blocks are, to all appearances, in no respect inferior to those made under the dry process. They cannot be turned over until they have been made for 24 hours, but the sides of the mould can be removed immediately after manufacture, the block remaining on its pallet, which can however, be removed the next day. The quality of the lime ordinarily used, in the upper part at least of the 2nd Division, is in no way superior to that used by Mr. Nielly, for the lime was burnt and the blocks manufactured without the benefit of that close supervision that Mr. Nielly has at all times given to such work.

In one respect only does the dry system seem to possess an advantage, viz., in rapidity of setting: no block made under the wet process could be placed in a rapid or under a fall within three months after manufacture, whereas Mr. Nielly's blocks can be so placed within a few days. But while admitting the increased rapidity of setting, I must point out that the ultimate strength of such blocks has not yet been proved superior to those made with more water and less lime.

I do not at all underrate the great importance of making blocks that harden immediately. The capacity of hastily making such blocks would in many cases be a great gain, and there can be no doubt that all concrete work put into falls during canal closures should be executed on the dry system. Mr. Nielly's successful application of the system to the manufacture of kankar concrete is a real gain, and he deserves great credit for the assiduous attention that he has paid to the subject, especially as his practice in this matter of watering is at such utter variance with what has hitherto prevailed in these parts. But the process having been now firmly established, I think it a matter for consideration whether more water and less lime might not with advantage be used in those cases in which blocks are made up some months before they will be required for use. The question of comparative strength remains for experiment, but the comparative economy of the older system is a matter of certainty.

Mr. Nielly has also attempted the manufacture of artificial cement, and references are made to the subject in his Reports D and F. In the former, he states that he has obtained a cement showing a high degree of hydraulicity, but compares it with no standard. In the latter, the tenacity of this cement is given when one year old at only 51 lbs. per square inch, which is much less than the ordinary Batála kankar lime one month old, which is given at 61 lbs. An apparently better result is obtained by mixing it in equal parts with kankar lime, the tenacity in this case being 93 lbs., but even so, 82 lbs. has been obtained with kankar lime alone at the same age.

The cost of this cement is given in Report E at Rs. 238 per 100, and it is assumed that by the use of proper machinery on a large scale, it might be manufactured at Rs. 50 per 100; but the data furnished for such an assumption are very vague. Kankar like the Hoshiárpur tufa, said to contain 88 per cent. of carbonate of lime, might possibly furnish a good cement if combined with clay artificially, but the necessary conditions for making such a cement economically certainly do not exist on the Bári Doáb Canal, and the attention of experimentalists may be far more profitably directed to improvement in the manufacture of lime from the excellent kankars obtainable throughout the whole length of the canal.

In conclusion, I would state that a lever has been recently made up, under which briquettes, or specimen dumb-bells of limes and concrete, can be made up under a uniform pressure, which is a matter of great importance in comparing specimens of different composition. These will all be submitted to tests for tenacity—a test to which attention has only recently been directed. The specimens will include some made of fresh white lime and súrki, the relative value of which to kankar lime awaits determination. The white lime and súrki collected some time ago for the remodelling works will also be tested, as it is important, before commencing work, to be assured of the real value of the materials available.

T. H.

III. Note by Lieut.-Colonel H. A. Brownlow, R.E., Supdg. Engineer, Upper Bari Doab Canal Circle.

Mr. Nielly's reports on limes and concretes are accompanied by an admirable summary drawn up by Mr. Higham, Exec. Engineer of the Special Works Division. Mr. Higham's own remarks and suggestions are very valuable, and I agree most fully with him.

Mr. Nielly deserves all credit for the unfailing interest and attention bestowed by him upon the subject of limes and mortars, for his persistent advocacy of the value of the kankar limes to be found along the upper portion of the Bári Doáb Canal, and for his successful manufacture of a very superior concrete on principles diametrically opposed to those previously accepted on the subject.

Mr. Higham's remarks on the "wet" and "dry" processes of concrete-making, (in pages 165, 166) are very good. The great advantages of the dry system are rapidity of hardening and, I should say, greater possibility of condensation; its disadvantages are its greater cost and the greater amount of supervision required in manufacture.

The relative tenacities of concretes prepared under the two systems have yet to be tested, and any marked superiority in this respect would weigh very heavily indeed in favour of the stronger.

Future repairs below water-line of masonry works on the canal ought invariably to be executed with good, well cleaned and burnt kankar lime, picked free from ashes and *ground dry*, no water being on any account mixed with it until it is just being put into the work. Too much importance cannot be attached to the latter condition, as nothing is more common than to see kankar lime being ground for hours in a common "*chakki*" full of water, and sometimes even the lime of yesterday's wet grinding being chafed up for to-day's work. All concrete laid down below water-line during a canal closure should, as recommended by Mr. Higham, be executed on the dry system of manufacture.

H. A. B.

No. CCXXVI.

PRACTICAL NOTES ON THE CONSTRUCTION OF HILL CART-ROADS.

[*Vide* Plate XXIV.]

BY F. H. ASHHURST, ESQ., *Assoc. Inst. C.E., Assist. Engineer, Military Works, Ránikhet.*

[The following Notes are the result of experience gained in carrying out orders received from time to time in the II Ránikhet Division, Military Works.]

I. Selection of Route.—This will, of course, depend so much on local circumstances, that few, if any, practical rules can be laid down, but it will generally be found that one side of a hill is easier to work on than the other. Thus, at Ránikhet, the southern and western slopes are generally the steepest and most expensive for road making.

It will also be found desirable to go occasionally out of the direct route, to pass near good building or camping ground, where there may be a plentiful supply of water.

A camping ground will be required at least every 10 miles, which is a long march in the hills.

If the ascent is steady, (without any "give and take" in the gradients,) 7 miles will be found quite long enough for a march.

II. Lining out, Gradients, &c.—In lining out the road, *two* pegs are required at each level-point, one driven down to the proposed cutting line, and the other (about six inches from the first) standing some 2 feet out of the ground to mark the position of the level peg, which would otherwise often be difficult to find.

These marking pegs should be coloured *red*, or some other distinct colour, on either side of ravines, or other places where bridges or drainage-culverts are to be built, to show the excavators how far they may go without interfering with the foundation work for the bridges or culverts.

The *steepest* gradient *advisable* is 5 per 100, but sometimes as much as 7 per 100 will be found necessary for short distances. No loss of gradient should be incurred if possible, except in giving 200 yards or so of level, every now and then, as a rest for draught bullocks.

In giving the cutting line, the pegs should be put down at a somewhat less gradient than is actually required, as in cutting off corners the road will be shortened.

For narrow roads the whole width required may be cut out of the hill-side, but generally the outside of the road will be of made earth.

The average amount of solid cutting required to form a 12 *feet road* is 7 *feet*.

The average safe side slope of cutting may be taken at ½ (horizontal) to 1 (vertical).

The *ruling* gradient in setting out a first class road should be from 3½ to 4 per 100, which in cutting of corners and subsequent improvements, will be found to work out to 5 per 100 in many places.

III. Cross Section.—The general rule on the Rámnugger and Ránikhet cart road from the plains, is to make the road surface *curved* where the height of outer retaining wall (if there is one) does not exceed 5 *or* 6 *feet,* and in all other places the entire surface to slope inwards with an inclination somewhat greater than the longitudinal slope of the road. The two cross sections are shown in *Plate* XXIV.

In *Fig.* 1, the full width of road is shown, viz., 20 feet, of which 2 feet is the width of parapet, and 2 feet also for the side drain, leaving a *clear* width of 16 feet for roadway. In *very difficult* places on the Rámnugger road, 11 feet clear roadway has been accepted, but as a general rule, even for minor roads, nothing less than 12 feet clear should be adopted, otherwise carts will damage the parapet, or go into the side drain. With a narrow road, frequent passing places will be necessary.

For the curved surface (*Fig.* 1), the highest point is one foot nearer to the parapet than to the side drain, and it is a segment of a circle with versed sine not less than 6 inches.

IV. Masonry Works.—In the Ránikhet Division, the stone is generrally so flat-bedded, that all breast and retaining walls and culverts up to 4 feet span are built of dry masonry. For 5 feet culverts and above that, the stones must be arched and set in lime mortar. The clear width of pucka bridges should be 12 feet between wheelguards.

(1). *Breast Walls.*—These are *very* important, and if built directly the earthwork is finished, will save a great deal in maintenance by preventing slips. The thickness of course depends on the nature of the soil to be protected or supported.

On the Rámnugger cart road, a thickness of 2 feet to 2½ feet at top, with back vertical, and a face batter of 1 in 3, has generally been found sufficient, though sometimes the face batter has been increased to 1 in 2, and the top made 3 feet thick.

The height should be such as will reduce the slope of hill side to its natural angle of repose, which has been found to average 8 feet above road surface. These walls are built of the largest procurable blocks of stone laid dry, at right angles to the face batter, and with the longest side inwards. As soon as the wall is finished, the slope above should be neatly dressed and prepared for turfing, and catchwater drains cut at a safe distance from top edge of slope, leading into the nearest ravines on either side.

(2). *Retaining Walls* to retain the made earth on the outside of the road and to carry the masonry parapet, are required along the whole length of road, except where the slope of the hill side is very flat. The usual section in the Ránikhet Division is shown in *Fig.* 2. They are built, like the breast walls, of dry coursed rubble in large blocks, with courses at right angles to the face batter. The top is 2 feet thick, the back vertical, and the face batter 1 in 4. In setting out these walls, which are seldom straight for any length, the pegs should represent the *back* of the wall, as this being vertical, will give either the foundation or the parapet *inside line.* Retaining walls give a good deal of trouble in maintenance, as they are much more liable to fail in the rainy season than breast walls.

(3). *Parapets.*—Unless these are built of very large blocks of stone, they are worse than useless, as the cartmen pull them to pieces to get stone for their temporary *chúlahs* on the march. They should average 2 feet wide and 2 feet high, and be built in 20 feet lengths, with 4 feet openings for drainage and clearing slips. If only small stones are procurable, the parapet should be covered with earth and turfed. This has a pleasing appearance.

(4). *Culverts or Scuppers* for surface drainage will be required at average intervals of 200 feet along the whole road, unless some bridge across a ravine intervenes to carry off the drainage, or the hillside be unable to stand the scour. The minimum size for these cross drains is shown on *Fig.* 2. The floor should slope not less than 1 in 6, and a catchpit 3 feet square, with floor one foot below floor of drain, should be provided to catch the silt washed down the side drains. This catchpit must be lined with masonry, unless cut out of solid rock.

(5). *Causeways or Pavements* are sometimes built for economy across large ravines in place of bridges. The drop wall must be set in lime mortar, and the pavement should be of the largest procurable slabs, or stones-on-edge pucka pointed. During fine weather these depressions should be filled up level with the road, and during the rains great care must be taken to prevent the rush of water from the ravine running down the road instead of over the causeway.

V. Side drains, turfing, &c.—(1). The *side drain* should be 2 feet wide at top, 1 foot at bottom, and 1 foot deep for roads 16 feet wide, or more, but 1½ feet wide by 9 inches deep is sufficient for a 12 feet road.

(2). *Catchwater drains.*—These are *most important*, and if cut as soon as the earthwork is finished, they will prove most useful in preventing slips. They should not be less than 3 feet wide by 2 feet deep, and should be kept at a safe distance from the top of slope, and discharge into ravines on either side.

(3). *Turfing* should be done during the rains, either by laying sods of grass securely pegged down, or by leaping the surface with a mixture of stiff clay and cowdung, to which a quantity of chopped *dúb* grass, quite fresh, is added.

Turfing is not only useful in preventing slips, but also adds very much to the appearance of a road.

(4). *Wheelguards* are very necessary to protect dry stone parapets and to keep cart wheels out of the side drain. They may be either of *stone* or *wood.* On the Rámnugger cart road, wood has been found to answer best. The posts (*see Fig.* 4) are 4 feet long, let 1½ feet into the ground, and the top neatly dressed, rounded and painted. They should not be less than 8 inches diameter.

(5). *Mile-stones.*—On the Rámnugger and Ránikhet roads they are of Agra sandstone, 2 inches thick, let into cutstone bases. Great care should be exercised in selecting their positions, which should be sometimes on the outside and sometimes on the inside of the road, and occasionally it will be found necessary to put the stone several feet from its correct position in order to avoid treacherous ground. The stones are 2 feet 9 inches high above the masonry base by 1 foot 6 inches wide, let 1 foot 3 inches into masonry base, and cost complete about Rs. 11-8 each.

(6). *Metalling.*—Only certain portions of a hill cart road will require metalling, such as very clayey, or very sandy places. The metal is obtained from boulders in ravines, or from veins of quartz in rock. The section of metalling used in the Ránikhet Division is shown in *Fig.* 1. The templates are made 7½ inches high in middle, and 4½ inches at sides and 12 feet wide, with a straight bottom.

It has been found necessary to have a 3 inch slope from centre to sides, so as to keep the metalled surface dry in the rains.

The amount of clay mixed with the metalling to bind it is ¾-inch over the whole surface, (*i. e.*, ⅙ of the stone) added in three equal portions to the stone.

The roller should not be a very heavy one, as it has to be moved about from place to place a great deal. A 3½ feet diameter roller 3 feet long, lately received from Roorkee, for the Ránikhet roads, has answered admirably. Its weight when empty is 30 maunds, and about double that when full of water. But rollers rather heavier than this are not inconvenient.

(7). *Water supply.*—Every perennial spring on the line of road should be turned to good account, by leading the water into tanks on the road-side. Two tanks are required at each spring, an upper one from which pure water can be had for drinking, and a lower one for cattle. The tanks on the Rámnuggor road are built of pucka masonry lined with Portland cement plaster. They are of any length convenient, and the cross section is as shown in *Fig.* 5. The head of the spring should be carefully protected by a fence, and trees planted if necessary inside this fence.

It will sometimes be found necessary to bring water to the road from a long distance. This can be done at first, by wooden troughs cut out of small trees, to be afterwards replaced by masonry channels or iron pipes.

VI. Maintenance.—The expense of maintenance will depend in a great measure on the amount of trouble and expense incurred in the original construction. Thus, a false economy in breast walls, catchwater drains, &c., in first construction, will involve great expense in maintenance.

For a well constructed road, a gang of 12 men with a mate should be sufficient for 10 miles of road, as their only work will be to clear out the drains and fill up ruts, but in the rainy season special gangs will be required to clear slips. If the slips are numerous and heavy, these gangs will only be able to keep a minimum width of road open for traffic, leaving the larger portion of the slips to be cleared away when the rains are over.

One of the greatest difficulties in maintenance is to find quarries for repairs to masonry works, as stone taken from above the road is apt to cause slips, and from below the road the raising of large blocks becomes difficult.

All footpaths, or cattle tracks should have small bridges across the side drain, which otherwise quickly fills up.

VII. Rates.—(Rámnugger and Ránikhet Roads).

Ordinary earthwork, ...	= Rs. 2 to 3 per 1,000 cubic feet.
Stony soil, ...	= „ 4 to 6 „ „ „ „
Rock, ...	= „ 6 to 20 „ „ „ „
Dry stone walling in breast and retaining walls, &c., ...	= „ 3 to 4 per 100 „ „
Digging side drains, ...	= „ 1-8 to 5 „ „ running feet.
Dressing and finishing surface of road, including earth parapet, ..	= „ 2 to 3 „ „ „ „
Small dry stone culverts, (2 feet to 4 feet clear span,)	= „ 20 to 50 each.
Large dry stone culverts *with long face walls*,..	= „ 100 to 200 each.
5 feet pucka masonry bridges, 12 feet	= „ 500 each.
clear width between wheelguards,	= „ 750 „
7½ feet do. do. do.,	
15 feet do. (finely cut masonry),	= „ 1,500 „

NOTE.—Or, roughly speaking, Rs. 100 per foot of span from 5 feet to 25 feet span.

For pucka masonry bridges from 25 up to 40 feet span, the cost is approximately Rs. 150 per foot of span.

Dressing and turfing tops of breast walls, &c., ...	= Rs. 0-8-0 to 1-8 per 100 square feet.
Metalling, ...	= „ 6-8-0 to 9 „ „ cubic feet.
The cost of a first class 12 feet cart road recently made *in* Ránikhet, with *all* masonry works of dry stone and no metalling, and no large bridges, ...	= „ 50 per 100 running feet.
Foot paths, 3 feet wide, ...	= „ 0-8-0 to 1 per 100 running feet.
Bridle paths, used as feeders and short cuts to cart road, 4 feet to 10 feet wide, ...	= „ 2 to 10 per 100 „ „
The cart road through Ránikhet Bazaar, 24 feet wide, and dry masonry works only, (over easy ground),..	= „ 90 per 100 running feet.

Stone-on-edge drain, 2 feet wide (for flooring of scuppers, &c.,.. ..	= Rs. 0-2-0 per 100 running feet.
Wheelguard posts, dressed, painted, and fixed, complete, ...	= „ 0-2-0 each.

The *total* cost of the 56 miles of cart road from Rámnuggcr to Ránikhet will be approximately as follows:—

		RS.
(1).	*Actual cost* of 16 *feet road* (clear width), including pucka masonry bridges, dry stone culverts, metalling certain portions, as well as two 1*st class* and two 2*nd class* Inspection Bungalows, &c., ...	= 6,91,732
(2).	*Sanctioned Estimate* for two large Suspension Bridges over the River Kosi, with spans of 292 feet × 212 feet, respectively, (not yet commenced,)	= 3,14,636
(3).	*Probable additional outlay* requisite to make the road suitable for *fast* traffic (say), ...	= 50,000
	Grand Total, ...	10,56,368

or, Rs. 18,860 per mile (for 56 miles).

VIII. General Remarks.—Cuttings should always be avoided if possible, as they are very troublesome to keep in order. They should always have a curved roadway with drain on each side, and catchwater drains above.

Neat and regular curves in side slopes, drains and parapets, will add very much to the appearance of a road.

At sharp corners, the slope of hill side should be as flat as possible, so that one may see round to the other side.

As excavators, Cabulís will be found to be the neatest and quickest workmen for earthwork, and they have generally accurate eyes for gradients and slopes.

In building culverts over ravines, the natural slope of the water-course should not be interfered with.

In filling in behind dry stone walls of any great height, only stone rubbish should be used; clay will swell if it gets wet, and throw the wall down.

In setting out a hill cart road from the plains, it is most important to get out of the low lying valleys as rapidly as possible.

As soon as a good approach from the plains has been secured, the road should ascend to 4,000 feet above sea level, without losing any distance, as any height below this will be within the influence of malaria at certain seasons of the year.

12th September, 1876. F. H. A.

No. CCXXVII.

NATIVE LATRINES AND POUDRETTE.

[*Vide* Plates XXV., XXVI. and XXVII.]

By a District Engineer.

THIS unsavoury subject has an economic aspect which makes its consideration a matter of much consequence. The effective and remunerative disposal of sewage is, in Europe, the question of the day, and is exercising the minds of the ablest Chemists and Engineers. In India generally the subject has been but little considered. There is a vast amount of apathy, prejudice, and ignorance to be overcome before the natives of this country will adopt the system of the Chinese and Japanese, of which an account will follow.* Even European countries have only very recently awoke to the fact, that the usages of the seancient nations are in strict accord with the principles of scientific agriculture. We must, therefore, not be impatient if the Indian ryot declines, without any very visible demonstration of its truth, to accept our views of the matter. Municipal Corporations, Military Cantonment Committees, and their Engineers, should, on these subjects, be the practical educators of the people.†

It is proposed here to place on record three types of Native Latrines, which have recently been designed and erected, and to note certain facts regarding poudrette, which ought to be widely known. The three types are—

I. Latrine for 8 persons, in which the evacuations are united. (Circulated by Local Government).

* Quite an unique case of the employment of refuse as manure by the Kachies of Furukhabad is most interestingly described by E. C. Buck, Esq., B.C.S., in the Agricultural Gazette of India

† Dr. Cornish, Sanitary Commissioner, Madras.

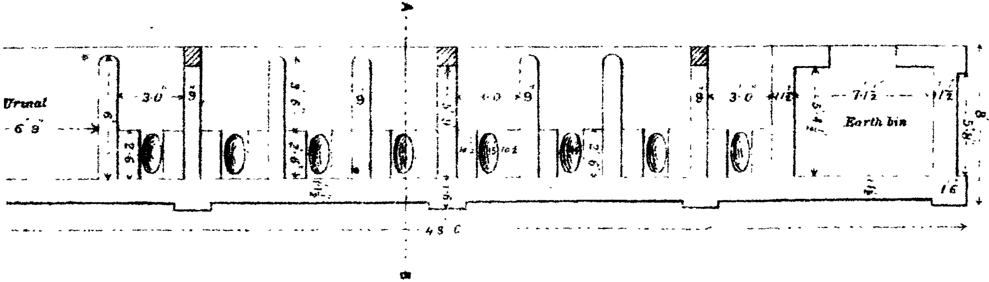
NATIVE LATRINES AND POUDRETTE.

Native Latrine in which the evacuations are united.
Scale. 8 feet = 1 inch.

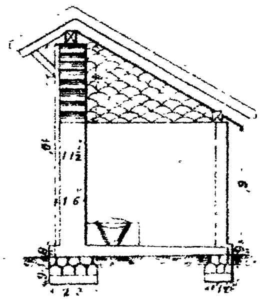
CONSTRUCTION.

Walls brick in mortar. Floors of Urinal asphalted—of Latrine, brick jelly tamped and tarred. Roof teak wood and tiles.

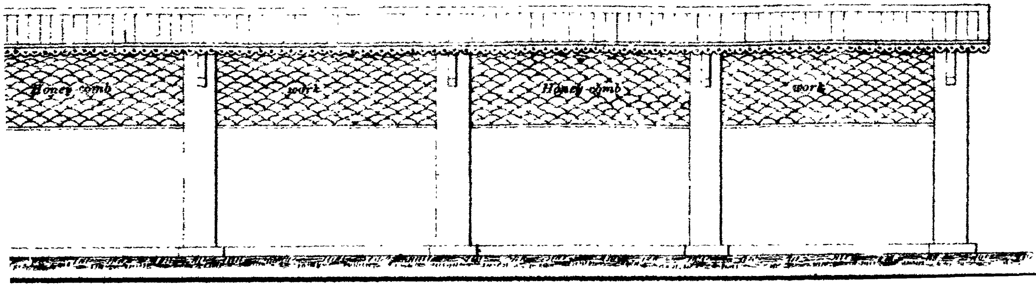
	£	s.
Cost per seat, ...	18	15
Of whole Latrine: ...	150	0



SECTION ON AB.



REAR ELEVATION



II. Latrine for 14 persons, in which the alvine and renal excreta are separated. (Circulated by Local Government).

III. Latrine for 16 persons, (10 males and 6 females,) which combines the manufacture of poudrette.* (Introduced in a certain Hill District).

I. *Latrine in which the evacuations are united, (vide Plate* XXV.*)*—Here the whole of each individuals defæcation is received in a large pan, covered with earth by the sweeper, and removed when necessary. It should have a front screen wall. This design is so simple as to need no further remark.

II. *Latrine in which the alvine and renal excreta are separated, (vide Plate* XXVI.)—In this design each native squats over the line of junction of two inclined planes, sloping away from him to the front and rear, down which the substances voided pass. The fæcal matter falls back into a paved space, from whence it is removed by the sweeper. The urine flows into a channel in front leading to a well, in which is placed a tub to catch it. The separation of the solids and liquids is said to diminish the quantity of earth or ash used as a deodorizer, and to facilitate removal: but Mr. Molesworth considers that the disadvantages of separation outweigh its advantages, and that a liberal supply of earth gives more satisfactory results.† The Local Sanitary Commissioner states that this latrine in practice works better than any other form of latrine for natives with which he is acquainted. The following is the very interesting official Report which accompanies this admirable design:—

The latrine has been designed to suit the habits of the Native population of both sexes; it admits of their using the building and washing, as is most natural to them, out of doors, while the most modern improvements for deodorization and cleanly removal of solid and liquid fæcal matter have not been lost sight of.

No arrangements have been made in or near the building for the manufacture of poudrette; however, vats and sheds for the purpose could easily be provided in localities where poudrette is in such demand as to offer any chance of revenue therefrom.

The area covered by the building is 750 square feet; it is calculated to afford accommodation for 14 persons at one time. The building contains—

One central sweepers' passage 35 feet × 3 feet; two sets of latrines, each containing 7 compartments 3 feet × 3 feet, with passages of approach 3 feet in width.

Each compartment is provided with a raised platform 10 inches in height, with central trough 9 inches in width, and from 6 inches to 10 inches in depth, with slight inclines in front to admit of the free flow of urine to a drain leading to tubs placed outside to receive it, and in rear for the easy removal of the earth-covered fæces by the sweepers to the central passage.

* *Poudrette*, a French word meaning "dessicated night soil."

† *Vide* Indian Engineering, (First Series, 1870,) Vol. VII., page 340.

Four earth bins, each containing 25 cubic feet, are placed so as to be accessible to the sweepers from their passage, or to persons using the latrine. Each bin to be provided with an earth-scoop to lift about 1 lb. of earth.

Two iron tubs for the reception of urine, and two wooden tubs with covers for its removal are provided. The requisite tools are provided for the sweepers.

The entrances are all screened, and at each end an easily accessible cistern to contain 32 gallons of water is provided, while the building, though well sheltered from rain, is thoroughly ventilated.

The mixture of asphalte and tar to be used on the floor, trenches, compartments, and all walls to a height of 3 feet all round inside, soon becomes indurated, and thus can be easily washed when necessary.

The cost of repainting all troughs and drains with this mixture once monthly is included in that named for conservancy.

In the conservancy of the latrine, earth about one inch in depth is placed by the sweeper on the rear incline of the trough; when used the fæces is covered with earth by the sweeper, and when necessary removed down the incline with a wooden rake into the sweepers' passage, where, if requisite, more earth is mixed with it, and the whole at certain times during the day carted away. The urine tubs are also removed when necessary by the same carts to the poudrette depôt.

As it may be useful to state the work required to be done, and the establishment necessary to work these latrines successfully, the following note is appended :—

From the data obtainable on the subject published in various Proceedings of Government from time to time since 1868, 3 lbs.* of dry earth is deemed sufficient for the perfect deodorization of the daily defædation of an adult which equals 5 ozs. of solid and 10 ozs.† of fluid excreta, or nearly 1 lb † To this, however, has, in the case of natives, to be added about one pint of water used for ablutionary purposes, to absorb which at least 1 or 2 lbs. more of earth are required. To supply so great a quantity of dry earth and remove the poudrette, has been one of the chief difficulties in carrying out the dry earth system in latrines constructed for the use of natives; thus with the view of economizing the quantity of earth to be supplied, and reducing the mass to be removed daily, the latrine now designed is so arranged that the solid fæces alone is deodorized *in situ*, while the less offensive fluid excreta and water are received into receptacles conveniently placed for the purpose, and finally removed separately to the poudrette depôt.

Allowing for waste and the perfect cleanly removal of the solid matter, the quantity of earth used in these calculations is 1½ lbs. per head. The earth bins to be constructed are to contain 100 cubic feet of earth, 7,000 lbs. in weight, or sufficient for say 4,600 persons. Taking the time that the latrines will be mostly used as five hours in the morning and three in the evening, and each person occupying a compartment for from 10 to 15 minutes, the number of persons the latrine of 14 compartments is capable of accommodating daily is say 500, and the supply of earth would be sufficient for more than a week.

But, practically, take 100 cubic feet of earth as requiring to be supplied once weekly, 64 gallons of water daily, and 500 lbs. of excreta plus 750 lbs. of earth, and

* Surely this is double what is needed.

† Surely these are mistakes—46 ozs. of fluid excreta, and 50 ozs. in all would be nearer the mark. Baldwin Latham gives 2¾ ozs. of fæces, and 30¼ ozs. of urine—in all 39 ozs. per diem of a mixed population.

600 lbs. of water, or 1,850 lbs. of solid and fluid matter will have to be removed daily to the poudrette depôt, to an average distance of one-and-a-half miles, which would place the depôt outside most cantonments. One cart could easily make four trips a day to this distance, and thus one cart would be sufficient to meet the requirements of two latrines at a moderate distance apart, and once at least daily might supply when returning one load of fresh earth, and keep up the supply of this material without difficulty or extra cost, while two men sweepers would be ample to attend to the latrine. The cost of this establishment would probably be as follows :—

	RS.
Half cart-hire for one cart, at Rs. 30 per mensem, ...	15
Two men sweepers, at Rs. 6 each, ...	12
Tar mixture for troughs, drains, sweepers, passage-tubs, &c, ...	4
Total, ...	31

or about 1 anna per head per mensem for 500 persons.

The Specification will be found at the end of the article.

III. *Latrine combining the manufacture of poudrette.*—This latrine is on the dry earth system, earth and sifted ash of various kinds being used as deodorizers. It is essential that the earth be used dry, to effect which it is placed in a bin with a sliding cover. A shed for the storage of the poudrette is also provided. The latrine is so arranged, that each individuals' fæces are caught in a bucket with a broad projecting rim at its back and sides, the urine passing either into the bucket or falling in front of the seats into a channel on the *inner* floor, which leads with a sufficient fall to the poudrette vat. Occasionally dry earth is thrown by the sweeper into the buckets over the matter they contain, and the buckets are removed, emptied into the vat, cleansed at the outer floor, and (their bottoms having been covered with some earth) are replaced in the latrine. In the vat, which is first partially filled with earth, the fæces and urine are daily mixed with a sufficiency of the dry ash, and then worked up with rakes, spades or other implements into poudrette, which again is covered with a coating of ash ready to receive the next supply. The mixing must be done in detail ; not a great heap of excretal matters and then a large quantity of earth, but a little earth must be added every time the excretal matters are increased. Within the latrine a small dipping cistern is provided, through which a stream of water always flows along the *outer* floor of the latrine. This stream being led by pipes clear of the latrine, does not fall into the vat. The frequenters of the latrine are to be encouraged to wash themselves in this part of the latrine, so that the water they use may not pass into the vat. The men's portion of the latrine has also 12 urinals, each being screened, the liquid flowing down into the vat.

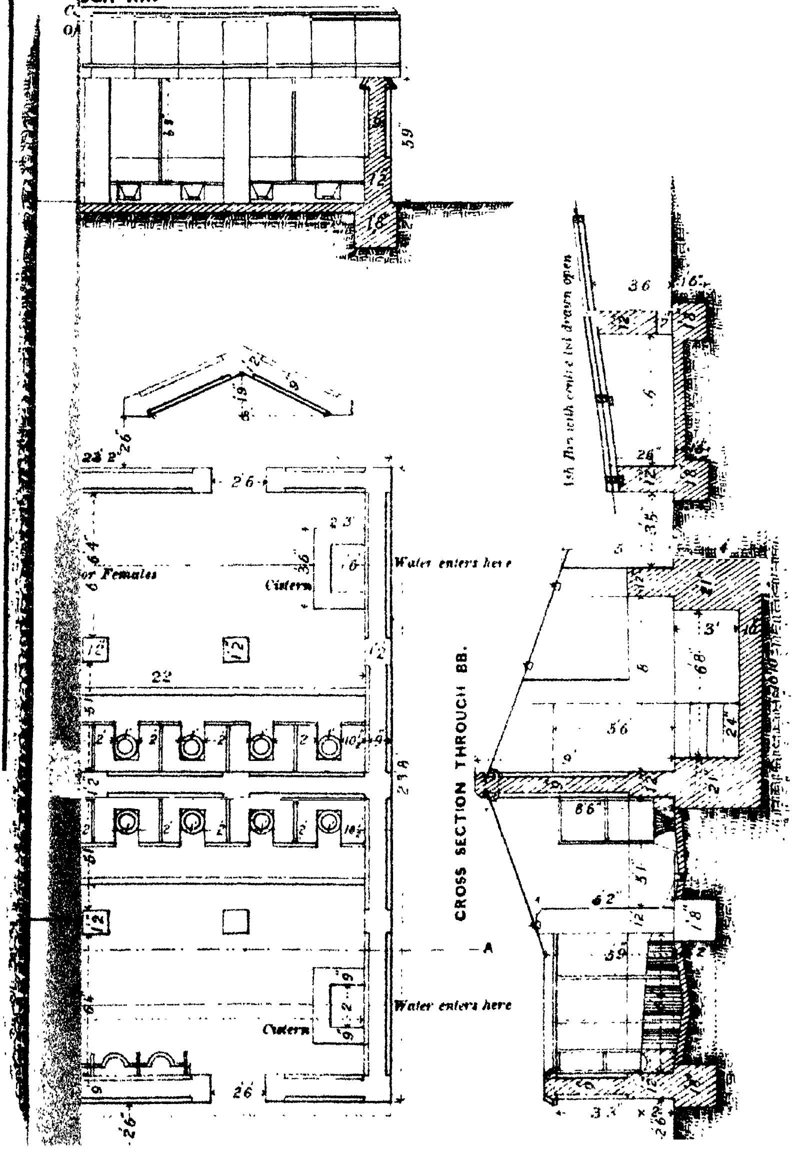
When the mixture in the vat has become thoroughly deodorized and the vat is full, the poudrette is taken out and thrown into the covered shed which has a paved floor sloping towards the latrine. Between the two there is a small well with movable lid and bucket, into which the moisture from the poudrette as it dries in the shed drains, the bucket being occasionally emptied into the vat. It takes no long time for the moisture to evaporate from the mixture stored in the shed. When this occurs, the compost becomes as odourless as common earth, and no excreta whatever can be detected in it, all extraneous matter such as even paper disappearing also, and, so long as it is kept dry, this earth mould remains quite inodorous. The poudrette can be kept in the shed until it is full, when the whole can be sold by auction. It ought to fetch at least Rs. 20 per ton. It has been found that 1 ℔. of dry ash will deodorize 2¼ ℔s. of excreta, from 1½ to 2 ℔s. of dry earth being required to combine with each individuals defædation. Almost any kind of earth will do except sand and chalk. It is often possible to employ the same earth repeatedly, if desired, so long as the one essential—dryness—is observed. It will thus be seen that both the alvine and renal excreta are caught and made into poudrette, little or no water being allowed to mingle with them; hence no valuable manure constituent is lost. The design illustrated has been constructed in two localities near a weekly market and Cantonment bazaar with marked success, the ready access to water for ablutionary purposes having been greatly appreciated. But every case must be carefully considered with all its attendant particulars: one general design can never without modification be universally applicable. In one of the places where this design was erected, it paid back its entire cost after deducting all working expenses and repairs in three years.*

* The following quotation, from the inspection notes of a Sanitary Commissioner, will forcibly show how greatly in some places latrines are neglected. "Impelled by a strong sense of duty I inspected the latrine in question and even penetrated to its extremest end. I was rewarded by finding an explanation for the fact, that the towns-people prefer to dot their fæcal deposits all over the ground surrounding the latrine, rather than enter its awful gloom. The door is so narrow that a stout bunniah might experience difficulty in entering. Escaping a plunge ankle deep into deposits made by some persons who had conscientiously striven hard to comply with the desire of the Municipality, but had been unable to get beyond the entrance, I penetrated into the building. It was dark, unventilated, and abominably offensive. At the far end to save appearances was a dry earth box; but there was no evidence ocular or nasal of the employment of any deodorant within a recent period. No sweeper was in attendance. Outside, a wooden box with iron lid had been constructed to receive the poudrette from the latrine, but it was empty: and one ingredient at least of poudrette remained within the latrine and around it. It is not possible to blame—" very justly observes the Commissioner "—still less to prosecute natives for declining to worship in such a temple of *Cloacina* as this, and until it is improved, any open space in the neighbourhood will be preferred."

ETTE.

y-comb work only in the Poudrette Shed. Roofs of corrugated iron
Plans, E is also laid on inside of walls and partitions up to 3 feet above floor.
for the use f corrugated iron.
combining

UGH AA.



In Europe, if blood be incorporated with clay so as to make a kind of paste the mass, instead of putrefying and becoming offensive, may be kept in summer at a temperature of 80° to 84° Fahr. for more than a fortnight, without giving the slightest sign of smell. The above fact suggests an economy and improvement of the value of the poudrette manure by the blood and other refuse from the town abattoirs, and the crushed bone and other rubbish, both animal and vegetable, from the town sweepings being mingled with the compost. In the Coimbatore District of the Madras Presidency, all the vegetable refuse daily swept from the streets is burnt to ashes in cinerators attached to each latrine, and the ashes are used to hasten the dessication of the solids and liquids, and to aid in forming the poudrette. Two samples of poudrette obtained from a latrine of the above kind mixed with crushed bone and blood were examined by two independent chemists at two separate periods, with the following results:—

Sample examined in 1873.

100 parts after drying contained organic matter, ...	22·63
" " " mineral matter, ...	77·37
	100·00

The following substances were found in 100 parts of the manure after drying:—

Bone earth, ...	10·28
Ammonic sulphate, ...	6·17
Potassic carbonate, ...	4·34

and its value was estimated at £5 per ton.

Sample examined in 1874.

One hundred parts of the manure as received yielded—

Water, ...	9·2
Organic matter, ...	20·06
Mineral matter, ...	70·74
	100·00

The following substances were found in 100 parts of the undried manure:—

Nitrogen, ...	1·50
Phosphoric acid, ...	2·64
Potassic chloride, ...	1·91

One hundred parts of the same manure dried at 100° Cent. yielded—

Organic matter, ...	22·028
Mineral matter, ...	77·972
	100·000

And the following substances were found in 100 parts of the dried manure—

Ammonia, ...	1·65
Phosphoric acid, ...	2·91
Potassium chloride, ...	2·13

We hence observe, how out of a community of human beings, all the waste products which in themselves are offensive and worthless, and have at all costs to be removed, can not only be disinfected, but converted into inocuous substances of sufficient value to yield a return in money much more than sufficient to pay for the means by which their conversion is effected.

It will here be useful to note certain facts relating to this subject, which are of sufficient importance to claim the attention of Indian Engineers.

The human body takes in the following :—

Food solid and liquid, containing in all 75 per cent. of water,	74·40
Oxygen taken in by the lungs, ...	25·60
	100·00

The above it gives out as follows .—

Water perspired by the lungs and skin, ...	34·80
Carbonic acid, ...	30·20
Evacuations solid and liquid, ...	34·50
Other losses, ...	0·50
	100·00

Thus the excrements are mainly derived from food. In his daily bread, man consumes the ash constituents of the grain from the flour of which bread is made: in meat he consumes the ash constituents of flesh. Chemical analysis demonstrates that the excrements of man contain the ash constituents of bread and flesh, very nearly in the same quantity as they exist in the food, which in the body undergoes a change similar to that which would take place in a furnace. The urine contains the soluble, the fæces the insoluble ash constituents of food, the stinking substances being the smoke and sort of an imperfect combustion.*

* Leibig.

Human urine consists in 1,000 parts of—

Water, ...	932
Urea and other organic matters containing nitrogen, ..	49
Phosphates of ammonia, soda, lime and magnesia, ..	6
Sulphates of soda and ammonia, ...	7
Sal ammoniac and common salt, ...	6
	1000

1,000 lbs. of urine, therefore contains 68 lbs. of dry fertilizing matter of the richest quality, worth in England, at least 10 shillings a cwt. Again, human urine contains as above 0·6 per cent. of phosphates, which are of great value as fertilizers. These are entirely absent from the urine of all other animals. The urine of two men is considered in England sufficient to manure an acre of land. Each full grown human being voids in a year at least one-twentieth of a ton of fæcal matter, and more than 1,000 lbs. of urine. The average amount of ammonia voided annually by an individual of a mixed population of both sexes and all ages is in urine 11·32 lbs., in fæces 1·64 lbs.; total 12·96 lbs.: and the estimated money value of the total constituents is in urine *7s. 3d.*, in fæces *1s. 2¾d.*; total *8s. 5¾d.* * Thus we see that the amount of valuable matter contained in the urine in the 24 hours is considerably greater than that contained in the fæces in the 24 hours. Weight for weight, the fæces are more valuable than the urine, but the total fæces are much less valuable than the total urine.

It thus appears that night soil is the most valuable of all animal manures. It varies in richness with the food consumed by the persons. In some of the towns of Central Europe this fact is so well known, that where a mixed population of Protestants and Roman Catholics live together, the neighbouring farmers give a larger price for the house dung of the Protestant families. In Persia, the night soil of the Russian families is, for a similar reason, preferred to that of the less flesh eating Mahomedans.

Poudrette to be sold as manure should consist simply of the dessicated excrements of man made into a transportable form with the ammonia, nitrogen, and other volatile substances fixed in it. Certain substances (such as ash, peat, saw dust, vegetable soil and earth, generally) are added to make it drier and more convenient for removal. All additions of the

* Corfield.

kind of course diminish the percentage of effective food elements, and increase the cost of transport. They should, therefore, be reduced to a minimum. The use of disinfectants in no way deprives the poudrette of any of its fertilizing virtues, as the following example will show. Some years ago, orders were issued by the authorities of the German town of Carlsruhe to disinfect the pits containing the poudrette with sulphate of iron before emptying them. The farmers who were in the practice of purchasing the poudrette took alarm, and at first refused to buy the disinfected article. But in time they found there was no cause for fear, and the disinfected dung soon commanded as high a price as the article in its purer state.

In Paris, Berlin, and other large Continental cities, poudrette is extensively prepared and exported in casks to other parts of the country. It is said to equal in efficacy 30 times its bulk of horse or street manure, and is applied at the rate of from 15 to 35 bushels per acre.* In London, Edinburgh and Glasgow, night soil is dried with various admixtures into animalised charcoal. At Rochdale (England) the excreta are manufactured into a portable manure at a cost of 14 shillings a ton; this manure commands a ready sale at 15 shillings a ton. Near Nice, poudrette is extensively put to orange trees and scented flower trees, and to other things which require a rich manure. At the Broadmoor Lunatic Asylum, at various English Schools and Jails, and at the annual camp at Wimbledon, the dry earth system of latrines has been tried with success and profit. In China, night soil is kneaded with clay into cakes, which are dried in the air and under the name of *taffo*, form an important article of export from all large cities of that empire. In Persia, it is dried in the sun and reduced to powder: mixed with twice its bulk of dry soil, it is then used for raising the finest melons.

In Germany, some most interesting and suggestive facts have been recorded by Leibig. In the Rastadt fortress and Baden barracks, the privies are so constructed, that the seats open through wide funnels into casks fixed upon carts.† By this means the whole of the alvine and

* In Paris, large cesspools, which take a year to fill, actually exist under each house. They are provided with ventilating shafts, and are emptied, when nearly full, by means of carts in which a partial vacuum is first created, so that when the hose connects the cart with the cesspool, the semi-liquid stuff rises up and fills the *tonneau*. The emptying of these pits is said to be a fearful nuisance.

† *Vide* Indian Engineering, (First Series, 1870,) Vol. VII., page 339.

renal excreta are collected without any loss. When the casks are full they are re-placed by empty ones. A cart complete costs £10, and lasts 5 years. The Army Administration in Baden in 1856 and 1857, (when the system was begun,) expended £370 on carts and casks. This sum was speedily repaid out of the proceeds of the manure. The collective number of the troops around Baden averaged 8,000 men. The receipts from manure sold in seven years averaged £500 per annum.* The annual cost of maintenance, repair of carts, &c., was £60. The food of the soldier in Baden consists chiefly of bread and of certain daily rations of meat and vegetables. Each soldier consumes 2 lbs. of bread, and there are 8,000 soldiers in all. Assuming, that 1½ lbs. of corn produce 2 lbs. of bread, the excrements of the soldiers in the Grand Duchy of Baden give annually the ash constituents required for the production of 39,055 cwts. of corn. The peasants around Rastadt and the other garrison towns, having found out by experience the powerful fertilizing effects of these excrements on their fields, pay for every full cask a certain sum, (annually increasing,) which has long since not only repaid the original outlay and covered the annual cost of maintenance, repairs, and working, but has left a handsome profit to the Military Department. The results of the use of poudrette in these districts are most remarkable. Sandy wastes around Rastadt and Carlsruhe have been turned into smiling cornfields of great fertility.

Human excrement in the form of manure is extensively used in Japan in a very wholesale and extraordinary manner. For, Japan is a country without a single head of cattle, without guano, bones, saltpetre or rape-cake. The only manure producer in Japan is man. In each house even of the poorest peasant, the privy—in the shape of a very clean neat cabinet nicely papered, occupies a position in the interior of the dwelling, out of the way of wind and rain. In this closet there is no seat but a hole through which the evacuations fall into a bucket or tub (often of earthenware) with projecting ears, through which a pole can be passed to carry the vessel. In some instances a layer of chopped straw is placed at the bottom of the vessel and sprinkled over the evacuations. As soon as the vessel is full, it is taken out and emptied into a larger vessel placed either in the outer yard or in the adjoining field. These vessels are large casks

* At Gröningen the yearly profit by the sale of poudrette amounts to £1,600, at Antwerp to £2,700, and at Ostend to £700.

or enormous stoneware jars of a capacity of 12 cubic feet, let into the ground nearly to the brim. In these the poudrette is prepared. The excrements are diluted with water, (no other addition of any kind being made to them,) and are stirred until the entire mass is worked into a homogeneous pulp. In rainy weather the vessel is covered with a moveable roof to shield it from the rain: in dry weather this covering is removed to admit the action of sun and wind. The solid ingredients of this mixture gradually subside and fermentation sets in, the water evaporating. By this time the privy pan is ready to be re-emptied. A fresh quantity of water is added, the whole mass is again stirred, and so the process goes on until the large cask is full. When this occurs, after the whole has been thoroughly mixed up, the mass is left for two or three weeks, when it is used in the adjoining fields with an addition of water in a liquid state. Under no circumstances is the manure used in its fresh state. The Japanese leaves the ammonia to be decomposed by the sun and volatilized by the wind, but takes the greatest care to shield the solid ingredients from being wasted or swept away by rain. To show how greatly the Japanese appreciate the value of this human manure, which can hardly be called poudrette, it may be stated that wherever his field is bordered by public roads or footpaths, he places casks or pots buried in the ground nearly to the rim, and *urgently requests the travelling public to make use of the same!* And so well is this call responded to, that a German traveller of repute, in all his extensive wanderings through the country even in the most remote valleys and in the homesteads and cottages of the poorest peasantry, never discovered the least trace of human excrement. In many parts of Japan also caravans of pack horses, which have brought manufactured articles a distance of two or three hundred miles from the interior to the Provincial capital, are sent home again freighted with buckets of manure in a dry solid state. And in other parts where water carriage is available, thousands of boats may be seen early every morning laden with high heaps of buckets full of the precious stuff, which they carry by means of canals from the cities to the country, these boats coming and going with the regularity of the post!! But this is not all. In the evening long strings of coolies are met with on the road, who having in the morning carried the produce of the country to the town, are returning home each with two buckets of manure, not in a solid and concentrated form, but *fresh from the privies!!!* The result of all this systematic annual manuring of the soil in Japan is, that the lands have yielded, in constant succession without intermission for thousands of years, good average crops. And the Japanese empire, which occupies an area equal to that of great Britain and Ireland though it contains a larger number of inhabitants, not only maintains them without any supply of food from other parts, but actually exports no inconsiderable quantities of food to other Countries; whereas, as is well known, England is compelled to import corn from foreign countries to the extent of many millions of tons per annum.

In India, some experience has been gained regarding the practical application and economic value of poudrette, which may be in conclusion noted here. It has been found that if the excreta are allowed some ten months to assimilate with the soil, any crop should flourish in ground manured with poudrette. Much depends on the chemical composition of the dry earth used to form the manure. At *Oomraoti* and *Sheagaum*, poudrette was tried on cotton lands with little or no result: this was attributed to the pulverized moorum and wood ashes which were separately used as deodorizers. Poudrette made with dried pulverized clay was very effective on strong coarse crops, such as sugarcane, jowar, sorghum, Indian corn, melons, cabbages, &c. The market gardeners at *Fatehgarh* have worked the pure night soil into their lands very effectually, and have raised three successive crops (Indian corn, potatoes and tobacco) a year on the same land. Poudrette mixed with other manure is very generally used at *Bangalore*, and is there well known and highly appreciated as a valuable fertilizer. At *Akola*, experiments showed that the outturn on land manured with poudrette at the rate of one ton per acre was 72 lbs. of clean cotton per acre, while land manured with bones yielded 99 lbs., and that with farm yard manure 77 lbs., unmanured land producing 26 lbs. The only obstacle to the speedy introduction of poudrette as a manure amongst the cultivators of Akola is their caste. They, however, acknowledge its excellence as a manure, but say, that if a field is manured with it, and there happens to be a scarcity of rain, the plant will burn up through the heating qualities of the poudrette, but that with an ample rainfall the manure is excellent. At *Oomraoti*, an acre of land deeply ploughed and manured with poudrette produced 101 lbs. of clean Hingunghát cotton, against an outturn of 25 lbs. from unmanured land.

From experiments in *Berar*, it appeared that it was far better to plough the poudrette deep under the soil for cotton, than to put it on as a top dressing. It was found to be in a great degree beneficial when coming in contact with the roots of plants. In the *Hyderabad* (Deccan) Jails, it proved an excellent manure when used sparingly or in a very stale state: large quantities of it used fresh caused the vegetables to burn up. The gardeners of *Sind*, who are *Banias*, are well acquainted with the use of poudrette; but the Mahomedans do not employ it. When used, it is sprinkled over the surface of the ground and applied to the roots of valuable plants, such as bang, tobacco and safron. In *Surat* and in *Nasick*, night soil mixed with ashes is sold to Hindú cultivators, who use it without the least prejudice. The health officer in *Bombay* reports, that he made "in "the rudest manner a manure by mixing fresh night soil in a pit with the "ashes of burnt town sweepings, and then spreading the mass by handfuls "in the sun to dry, which it did in a few days, this manure resulted in "an earth which was inoffensive to sight or smell." In the *Deccan*, night soil has long been utilized under the name of "*sonkhud*" or golden "manure." In *Oudh*, night soil has been used by native cultivators from time immemorial, with immense benefit to their crops. The public garden at *Chindwarra* in the *Central Provinces*, has always been manured with poudrette, and has long been noted for the abundance and excellence of its produce. In the *Raipur* public gardens (*Central Provinces*), peach trees were found to require poudrette once a year, guava and mulberry trees once every three years: the trees thus manured required copious waterings, owing to the latent heat of the manure. In *Bilaspur*, potatoes cut in halves were planted in trenches manured with poudrette, and the yield was more than five-fold, the size of the smallest potatoe being double that of those sown: potatoes sown in a similar manner with cowdung gave a return of only double the quantity put down, the potatoes of the crop being no larger than those sown. In the *North West Provinces*, there is a strong prejudice amongst the Natives against the use of poudrette. But from experiments in the Jail Gardens, it is found, that it is of great value, if left for several months to decompose in the ground, and to part with its fertilizing elements to the soil. Similar experiences have been obtained in *Bengal*. At *Trichinopoly*, human excreta from the latrines are freely purchased by the natives and applied with good results. On the *Neilgherries*, the town sweepings mixed with the night soil are in great demand for the coffee lands on the Conoor ghát. In the *Mercara* jail a certain quantity of Queensland maize manured with poudrette yielded 253·17 per cent. of grain, and 165·57 per cent. of straw, in excess of the yield from a similar quantity of seed raised with cattle manure. In the town of *Madras*, very large quantities of night soil are taken by the market gardeners and cultivators in the suburbs of the town, and the natives who grow plantains for the local market will actually come and *pick out the fresh night soil* out of the manure depôt heap and take that only, if permitted, in preference to the decayed manure.

Indian experience generally has shown that poudrette is more useful in such plants as contain sugar and starch, than in those of a more nitrogenous nature. This is explained by the more vitalizing effect upon these crops which the phosphates of the poudrette have in conjunction with the carbonic acid of the vegetable manure with which it is generally mixed.

Three points should be attended to in the use of poudrette.

1. Not to apply it too soon or fresh.
2. To add to it or mix with it some decaying vegetable matter such as leaves, straw, saw-dust, peat-dust, or ash.
3. To secure that it shall receive a good supply of water by rains or by artificial means.

The first point is common to all manures, but it needs the *more* attention in poudrette, because of the quantity of gases deleterious to vegetation given off by it if used too early. The second point of observance is peculiar to poudrette, inasmuch as without a due admixture of vegetable matter to furnish a due proportion of carbonic acid, the phosphates in which poudrette is rich are not utilized. The third point of plentiful watering is needful for due solution of the matters contained, and to present them in a form in which they can be absorbed by the plants.*

Specification to accompany Estimate for constructing a Latrine for the use of Natives.

Site, Excavation.—The site to be cleared of all grass, bushes, roots, &c., and after centre lines of the walls have been pegged out and breadth of foundations marked on ground, excavate trenches to the full depth shown on the plan, or to such depth as the locality may require.

Concrete.—To be composed of three parts of coarse gravel or kankar,

* Dr. Henderson of the Bangalore Central Jail.

two parts roughly broken bricks, one part sand, and one part of freshly burnt lime, mixed together with sufficient water to allow of its thorough incorporation.

Foundations.—Lay one layer of concrete, 6 inches thick, ram well, and level all round.

Brick and Mortar work.—Bricks, best well-burnt bricks, 9″ × 4½″ × 2¼″ well shaped with square edges, ringing clear, to be used. The bricks to be well wet with water before being used, and laid in proper courses, joints broken, and bond preserved throughout, care being taken that all the vertical joints are well filled with, and each brick well embedded in, mortar. The walls and honey-comb work between pillars to be bonded with pillars.

Mortar.—To be composed as directed in the instructions given in Dr. Nicholson's Report.

Put log holes.—Put log holes for scaffolding not to be placed in pillars.

Honey-comb work.—Open brick or honey-comb work, as per plan, to be built full width above walls between pillars as shown in the drawing; joints to be carefully made with best mortar, and all interstices left clear.

Arches.—All arches, where stone is obtainable, to be made by insertion of a flat stone over openings in rear of latrines, or regular turned brick arches.

Pillar caps.—Pillar caps to be, where stone is cheap and easily obtained, of stone, otherwise of timber not less than 3 inches thick, covering the whole area on top of the pillars, care being taken to lay all level.

Roof.—Roof timber to be of teak :—

Central bressummer	5 inches	×	8 inches.
Outer ,,	4½ ,,	×	7 ,,
Rafters	2½ ,,	×	4 ,,

The bressummer to be laid all level, and central bressummer tied by six iron ties with collars, nuts, &c., of the dimensions given in the detail drawing, and nuts well screwed home.

Rafters to be notched at ridge and nailed together, and slightly notched at bearing points on bressummers, and securely nailed to them. Rafters to be 18 inches from centre to centre. Then nail reepers 2″ × 1″ 4 inches apart, and tile dry with the best well-burnt pantiles; finish with chunam ridge, and borders 9 inches broad, 2¼ feet apart.

Flooring. Asphalte and tar composition.—At all entrances build in stone curbing as shown in the plan, fill floor of all passages with concrete as before specified, with slope from walls to drain ½ inch to 1 foot;

central sweepers' passage, concrete floor, to slope to centre as shown in plan; ram the whole well and finish smooth; when thoroughly dry, paint the whole with a composition of coal tar and asphalte in the proportion of 1 ℔. of asphalte to 5 ℔s. of tar.

Troughs.—Brick and mortar work of all troughs to be very carefully laid, and slope as delineated in drawing maintained; joints laid as close as possible, ends of bricks on apex of slopes to be ground to fit close.

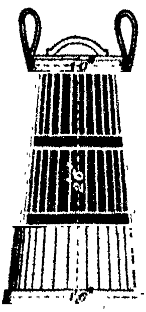
Platforms.—Brick and mortar work of platforms to be securely laid and bonded to the trough work, the whole to be well smoothed off. Stone where obtainable at cheap rates might very properly be used for the platform surfaces.

Drain.—Lay a V or tile drain securely bedded in mortar, sides level with floor as shown in the drawing, with a fall to the centre of 3 inches in 10 feet, and to out-fall gutter pipe which is to be of iron 1 foot in length, 3 inches diameter, projecting into the bucket wells 4 inches.

Water Cisterns.—Two cisterns, each to hold 32 gallons of water, to be built of best brick and mortar in the localities and of the dimensions shown on the plan, with stone coping firmly laid and cramped at the angles with iron cramps leaded in, the side pieces to be built at least 6 inches into the screen walls; the cisterns to be plastered with best súrkí cement, well polished, and kept wet and protected from the sun till firmly set.

Bucket Wells.—Build in brick and mortar, as per plan; paint with mixture of asphalte and tar, cover with wood, and build ledge to exclude rain.

Buckets.—Supply two iron buckets each to contain 6 gallons, with handles to allow of insertion of bamboo for removal, as per standard plan.



Supply two wooden iron-hooped tubs with covers, iron loop handles, as per drawing, to contain 18 gallons for the removal of urine to the poudrette depôt; paint with tar; supply two bamboos.

Painting with Composition.—Three feet up all walls inside, all compartments, division walls, earth bins, platforms, troughs, drain, &c., to be painted over with the asphalte and tar mixture with two coats.

Whitewash.—All walls and screens inside, above the tar paint, all honey-comb work, to have two coats of best lime-wash; the lime to be used hot and slaked on the spot.

Colour-wash.—All walls and screens outside to be colour-washed by mixing coloured earth with lime-wash composed as above.

Tools.—The following tools to be supplied:—Four iron earth scoops to lift 1 ℔. of earth, two wooden rake scrapers with blades 7″ × 5″ × 1″ and handles 4 feet long, 2 baskets, one broom.

Gravel.—The spaces between the main and screen walls of the building to be sloped away for easy drainage, gravelled and rammed.

Remove all rubbish.

Abstract Estimate for constructing a Latrine of 14 *Seats at* _

Quantities.	Particulars.	Rate.	Per.	Amount.	Total.
		RS. A. P		RS. A. P.	RS. A. P.
54⅜	Cubic yards, excavating foundations and filling in, ...		c. yd.		
17⅓	Cubic yards, concrete in chunam for floor and foundations, ...		„		
2,334	Cubic feet, brick in chunam, ..		c. foot.		
418	Square feet, honey-comb brickwork in chunam, ...		sq. foot.		
1,006	Square feet, roofing with nails, pan-tiles, chunam borders, &c., ..		sq. foot.		
87	Cubic feet, teakwood wrought and put up for bressummer and rafters,		c. foot.		
2,100	Running feet, teak reepers, 2″ × ⅝″,		r. foot.		
116	℔s. of iron wrought, ...		℔.		
2,572	Square feet, tarring composed of 1 ℔ of asphalte to 5 ℔s tar, ..		sq. foot.		
10	Square yards, of gravelling well rammed, ...		sq. yd.		
974	Square feet, white-washing inside and colour-washing outside, ...		sq. foot.		
119	Square feet, sárki plaster two coats to cisterns, ...		„		
18	Running feet, stone slabs 9″ × 7″, ..		r. foot.		
24	Do. do. 18″ × 3″, ..		„		
21	Do. do. 9″ × 3″, ..		„		
4	Iron cramps set in lead, &c., ..		each.		
2	„ buckets for urinary cisterns, ..		„		
2	Wooden buckets, large, ...		„		
2	Trap doors, including handle and zinc flashing, ...		„		
2	Iron gutter pipes 1′ long and 3″ diameter, ...		„		
2	Rake scrapes with blades 7″ × 5″ × 1″,		„		
4	Iron earth scoops, ...		„		
2	Baskets, ...		„		
1	Broom, ...		„		
	Superintendence and sundries at 5 per cent., ...				
	Total Estimate, ..				

J. L. L. M.

No. CCXXVIII.

SUTLEJ RIVER-TRAINING WORKS AT ADAMWAHAN.

[2ND ARTICLE].

[*Vide* Plate XXVIII.]

Report by E. B. MEDLEY, ESQ., *Exec. Engineer, and Notes by* M. RAYNE, ESQ., *Supdg. Engineer, and* COL. F. W. PEILE, R.E., *Engineer-in-Chief.*

Report on the Sutlej River-Training Works for the season of 1875, *by* E. B. MEDLEY, ESQ., *Exec. Engineer.*

THE Report submitted by Mr. Graham, late Exec. Engineer, Sutlej Bridge Division, describes the operations carried out from their commencement to about the end of September 1874. The operations to be described since carried out, will, I think, be more readily understood, if divided into the following heads, viz.:—

1st. Those operations undertaken during the cold season at low water level, and immediately depending on the ensuing floods for their effects. *For example*—construction and repairs to tree bunds.

2nd. Operations executed at ordinary flood time, but depending on higher floods expected for their effects. *Example*—attempts to direct main channel from a winding to a straight course, by scouring through shoal or sand bank—forming by means of 100 feet "net spurs."

3rd. Operations undertaken at the end of the flood season and continued on, to stop the cutting and undermining of the permanent bank, or for the protection of "sand banks" required for well sinking operations. The means applied being "weed spurs" with fascines and brushwood.

Under the first head, the following were the works executed :—

On north bank (Adamwahan side). Three new tree bunds about 600 running feet in average length each, were constructed below site of bridge

Also two tree bunds above site, making, with the two bunds of previous year, a total of seven bunds, made with the object of protecting bungalows and bank, and further to silt up the deep channel and bay made by the river years previously. The two bunds of the former year, just referred to, were also considerably strengthened and repaired.

At Goodpoora about 6 miles up-stream, right bank and above D bund, two short spurs partly of "weeds and trees" were also constructed, and marked D^1 and D^2.

At D the first "weed bund" made, the bushes had nearly all subsided in the previous floods. A new bund of trees and bushes was constructed about three or four chains in advance of remains of first bund. On the south bank, Bahawalpur side, the bunds marked L, E, C, F, G, B, A, were all considerably strengthened, and when subsidence had taken place, fresh trees or bushes besides new trongahs and rope material were substituted for the old.

A new "tree bund" was also constructed about quarter of a mile above A, to assist in diverting the scour from the latter. The new tree bund marked M, about three-quarters of a mile in length, was also constructed. This being the longest bund yet made, the amount of labour and material used on its construction was considerable. These "tree bunds" with the exception of some slight modifications to be presently noticed, were constructed as formerly, viz., with trees or bushes tied together with 8", 5" and 2½" rope, and weighted with trongahs or nets filled with brick, but having no casks as used in the construction of "weed spurs." The old material used on all the old bunds had mostly subsided or rotted away—new material had to be substituted almost throughout, with the exception of a fair quantity of the "brick" which was made use of a second time, having been recovered by digging up the old trongahs. One of the modifications in construction should be noticed here, viz., when the bunds constructed crossed the deepest water, that portion of the bund was doubled throughout. The object being to divert the heavy scour that had taken place previously from the old to the new portion.

On the subsidence of the floods, I went to inspect the above bunds, and the results of the silting up of the Nowrungah channel.

From the "Nowrungah mouth" (marked "dead water") to the mouth of the "Khanwah canal" about half way between E and C bunds, the silting up is very nearly completed. Where at the mouth it was from 18 to

24 feet in depth two years ago, an insignificant channel alone remaining, the rest being a sand bank silted up to within two or three feet of the surrounding country.

From the mouth of the Khanwah canal to F bund. Here the channel (having been left open during the season to supply water to the Bahawalpur State) has scoured out again to a depth of about 12 to 15 feet; C, F and F[1] bunds which were partly left opened, disappearing almost entirely. 300 feet of new bund will be required to restore C again; the rest of it on higher ground remaining intact.

From F on to B bund again, there is a channel 70 feet in width yet remaining to complete the silting up throughout this portion of the length. At M bund, beyond the trunks of all the trees are embedded in silt, the ground is high here, only the surface flow passes over it.

The channel where A bund crosses has almost silted across. Another bund, next year, about 100 feet long only, I think, will effect it. On the north bank at the seven bunds at Adamwahan, besides those at Goodpoora above described, the silting is almost completed. Of the three bunds below the "*site*," however, scarcely any of the material is left, having done, however, some good in silting up before subsiding. More good would have been done had not the ends of the bunds nearest the bank been destroyed to allow of "rafts" of sleepers to pass up. Some thousands of willow cuttings, I regret to state, disappeared through the mooring of the above rafts all along the bank.

The above being a description of the heavier works constructed, those of a minor description remain to be mentioned under the second head.

1st. As to the object to be attained, and

2nd. The means to be applied.

The object to be attained here was the straightening of the river's course by cutting or scouring a fresh direction for it across the shoals or sand banks by means of 100 feet nets.

The general character of the river, should I think be briefly referred to, in order to make the application of these 100 feet nets intelligible.

In its usual circuitous course, the river towards the end of the season is contracted principally to one channel. It then begins to cut and undermine the permanent bank, and to form a shoal extending nearly across from the opposite bank. If not checked either by natural or artificial means, the result is a "bight" or "bend" taken out proportionally extensive and mischievous according as the bank attacked is more or less sandy; almost exactly the same thing goes on at about every two miles, alternately setting from one bank on to the other; the one bend is affected by the next one higher up, and so on. Each shoal again seems in size dependent on the extent of the jungle or "pilchi" which growing along the edge of the bank at the immediate bend up-stream is carried down, and then arrested in slack shallow water, accumulating sand at down-stream bend. By making an experiment of cutting and removing the jungle first of all along the immediate bank in anticipation of its falling in, it is likely, I hope, that some good may result therefrom.

This action of the river as described above, continues on throughout the cold season, and remains so until the next season's floods, which rising and spreading, makes a fresh course for itself across each sand bank thrown up the previous season, the now new course of the river, being the old channel formerly frequented by it. This channel again widens out across the sand bank, and the cutting away of the now opposite bank goes on again as before. This describes the "general" course of the river only. To check this zig-zag course, attempts were made to straighten its course by means of nets, (100 feet × 3 feet,) the meshes being six inches square. To these nets were tied rope trongahs and casks as in the case of "weed spurs." The nets were placed "*en echellon*," and at a sufficient angle across the sand bank, so as to intercept a portion of the main stream coming down, and to guide it across in anticipation that at the next rise of the river to come, a scour, and eventually a channel would be created across the sand bank, giving the new straight course to the river desired. This plan was carried out in three places, viz., above spur F, below F, and at Lei-wahan, where the respective shoals had formed. These spurs were laid at a time when the river having fallen somewhat, left the shoals exposed sufficiently to work upon. The success of the plan was only partial; but the nets did check the direction of the stream somewhat above F spur, as at the time it was flowing on to the north bank at Goodpoora, which side it left to flow along the south bank, where, however, it was about then due in the natural course of events. Below F, where the nets were laid later in the season, an additional inducement was given, by digging a channel across the sand bank immediately above and along the "nets."

The two subsequent floods, however, which occurred did not create the result hoped for, as the channel remained closed, and the river still continues its course round the sand bank in preference to the straighter one marked out for it.

At Lei-wahan under similar circumstances, the river had been flowing from there on to the south bank above E bund. It had kept that course throughout the cold season around the sand bank it had formed. The river gradually rising, held the same on until August, and which it did not leave until half of L bund had been carried away. Before leaving this course, however, 100 feet nets (as at F) had been placed across the sand bank as above described.

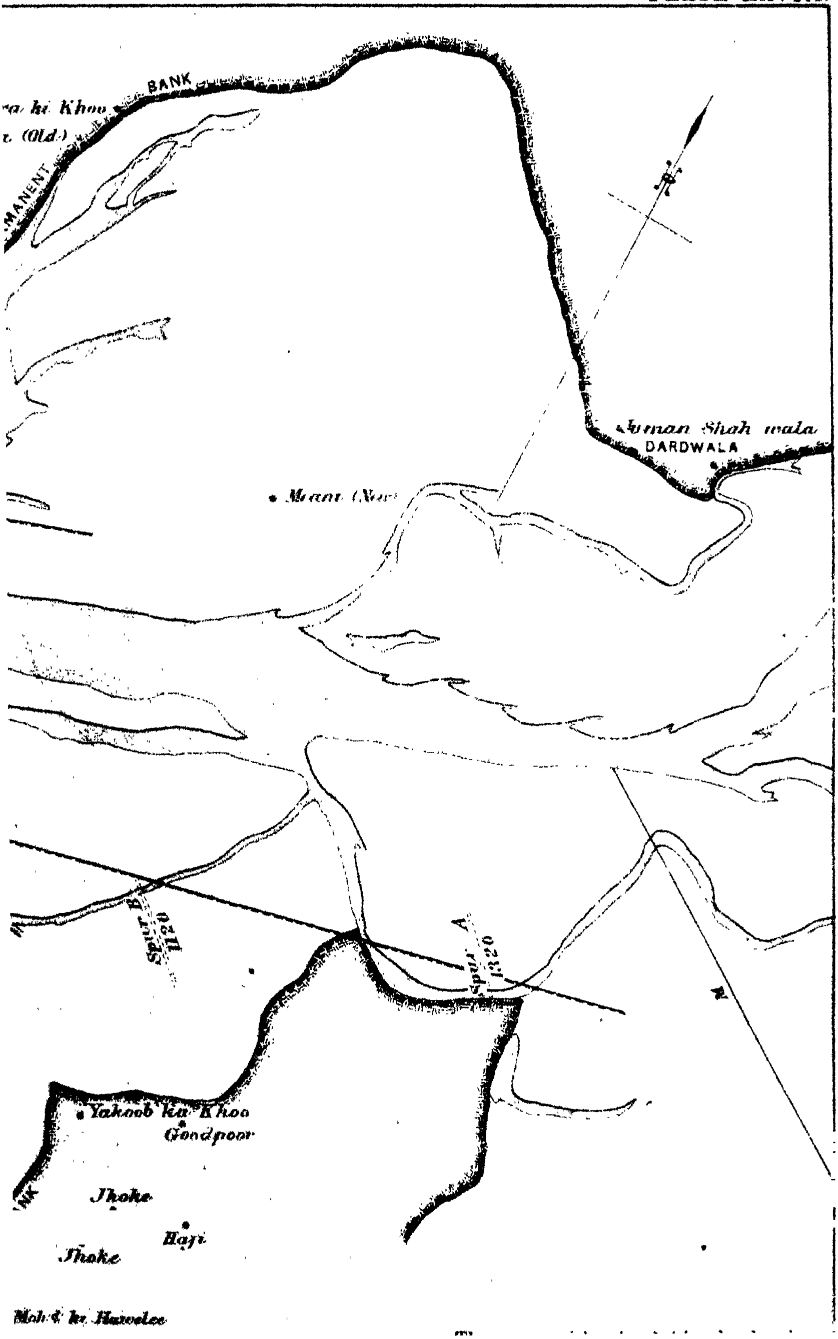
It is difficult to say to what extent the course of the river was affected by the 100 feet nets, and the resistance offered by L bund, because the change in its circuitous course was due at the time, and the change took place as above stated; the river now in its new course across the sand bank keeping close under the Lei-wahan bank, which it commenced to cut away with great rapidity. From this point the river's course now flowed down obliquely upon the bridge site, destroying in its passage the communications between P and Q piers, besides commencing an attack on the bank above the abutment wells. Measures were taken to protect this permanent bank, as well as to check the cutting at Lei-wahan in the way described below under the third head. Some net spurs were placed to try and silt up the disturbed communications between P and Q, as also to protect the bank above R pier. These nets put in with double casks one extra weighted, held well for some time in strong water, but eventually gave way before a rise in the river which followed soon afterwards. Although the attempt to preserve a sand bank on both sides of the river, the same as the previous year, was not successful this, nevertheless an extensive "sand bank" was thrown up extending on the one side (Adamwahan bank) right across nearly to the other, due to this sudden but not unexpected change in the river's course. This sand bank is as extensive for carrying on the well sinking operations as could possibly be desired, I believe.

Under the third head I have now to describe the system of defending the bank with "weed spurs."

These spurs were placed at about every two or three chains apart along the bank, in a strong current running a depth varying from 10 to 20 feet. The bank as it fell in from time to time was sometimes sloped in bad places, forming short "irregular" bights in between the "spurs" protected also by grass or jungle tied up into bundles, and allowed to drop along the toe of the bank, besides the projecting ends of the bights being protected with stronger brushwood. In this way at Goodpoora and along south bank, (at E bund) the whole length on both sides and over a mile in extent was protected throughout the cold season. The bank fell away considerably before the mischief could be stopped. This, it is hoped, will be avoided for the future to a great extent, by placing the spurs at a good angle to the bank, instead of at right angles which was formerly done. Two points along the bank attacked, since treated in this way, (viz., at Lei-wahan and above the abutment wells on south bank,) have resisted those readily since the encroachments of the river. A very large bight has been taken out of Lei-wahan it is true, but this would not have been so large had material been more easily available. As it was, the stock of material stored at different sites had been exhausted, and fresh material had to be dragged up river in boats against wind and current.

The second point above mentioned, above the abutment wells. The supply of material was more readily available, the spurs thrown out (about 20 in number) and 200 feet apart held, and not more than 200 feet of bank was carried away. I would, in conclusion, say a few words regarding the supply of "*material*" and "*work*" generally done, and to be executed for next season.

1st. As regards the supply of "*trees*" and "*bushes*" which has now been pretty nearly exhausted in the immediate neighbourhood of the river's banks. Our next supply will have to be procured from a greater distance at an increased cost. The various operations of cutting, loading, carting, unloading, and with water carriage besides, makes the cost, especially of large trees, to vary from Rs. 1 to 4 each. I would beg leave to suggest that the Forest Department be called upon to grow trees along both banks of the river. Trees of five years growth tied together where the bank happens to be cutting away, weighted with trongahs and casks attached to the lighter trees, all together would form "spurs" as effectual and more readily made in place of the unavoidable delay and expense that has to be incurred at present in procuring the trees from any distance. The land all along the south bank which the bunds from A down to L has silted up, could be made to grow a "forest of trees" about half a mile in width. Between Adamwahan and Lei-wahan there is similar waste land. Such trees as farash, babúl, date, kurreel and pillew, would, I think, readily


BANK
...a ki Khoo
...(Old)
...MANENT
Juman Shah wala
DARDWALA
Meani (New)
Spur B
1120
Spur A
1320
Yakoob ka Khoo
Goodpoor
Jhoke
Haji
Jhoke
Mohd ka Haweles

grow if only the seed was scattered broad cast. As regards the principal trees mentioned, some organization would be required for the first few months. Within the boundaries of the colony, I have already sown rows of trees along the bank and on the sand beds, and behind some of the bunds. 55,000 willow cuttings were planted. In most cases they have thriven notwithstanding the high floods which submerged them. This season they are being pruned, and the cuttings obtained planted out. I hope in this way with the assistance of the "tree bunds" protecting the willows, and silting up to make the Adamwahan shoal under the bank a forest of cuttings having deep root in the soil, and giving considerable strength to the bank. Many of them have now grown to a height of 10 feet with stems three and four inches in girth. They have been planted out, and extend from the bridge site to above old D spur.

Múnj rope material.—There is a large stock in hand at present, which, I believe, will go far towards the construction of bunds, &c., this cold season. As the "trongahs" for holding brick last only one season, I think it will be an advantage in point of economy to reduce the quantity of múnj rope used in their construction still further. I think a 12 feet trongah should not exceed 1¼ maunds, instead of from 1½ to 1¾ maunds as at present made.

Brick.—The stock in hand has been nearly exhausted. The contractor who made the bricks up river having failed, the rate will have to be increased from Rs. 10 to Rs. 12 per 100 cubic feet delivered. Up to present date no one has tendered even at that rate, and lately I have had principally to rely on the "peela" and overburnt refuse bricks obtained from Messrs. Collins and Petmann.

"*Casks.*"—There has been (taking the two years together) considerable loss sustained. Out of the original quantity of 3,400, only 1,500 remain on hand, the rest having broken away from their moorings or been sunk in the sand banks when used in their usual capacity in the "weed spurs" constructed. I hope to avoid the loss to a great extent for the future, by fixing wooden brackets on the casks, and to prevent thus the ropes buckling round, from slipping off, as they have *done* in numberless *cases I believe.*

NOTE.—"Brick." Since the above was written, a very important saving has been effecting, by my substituting bags of "date matting" filled with earth, in lieu of the "brick and trongah" formerly "used."

To anticipate the likelihood of the rivers attempting the Adamwahan side again, and indeed, I am aware of the necessity that may exist for endeavouring to force it over to some extent to this side, in order to complete the well sinking on the south bank: to anticipate any such set of the river in its full strength on to this side in addition to strengthening the existing "bunds" (which have of course subsided to some extent this year), they should, I think, be reduced in length and splayed off to an easy angle with the bank, and shorter "spurs" about 100 feet or more in length added in between. I would have them alternately of "weeds" and "trees," so as to prevent scour, as well as to check the surface velocity. The material could, of course, be transported elsewhere should these defence works be found unnecessary. Material should, I think, be laid all in readiness to near Lei-wahan, a length of 3 miles, *now* only partly defended. The 20 "weed spurs" lately put in here have checked the cutting, but they should be renewed at the end of the cold season, as the water still flows strongly over some of them, and the material will soon have sunk.

The spurs or the material for them should be, I think, at every 200 running feet, or 26 per mile. For 3 miles this would give a length of 7,800 running feet, which at Rs. 5 per running foot, including labour and material, would cost Rs. 39,000.

Material should also I think be placed in readiness to construct similar spurs along the south bank, between the "abutment wells" and the Nowrungah mouth, as soon as those now existing shall have done their work.

The distance is under half a mile. As most of the bunds along the Nowrungah channel from A to L are intact, and the channel almost silted up, it will not be necessary a second time to go to the expense this cold season of renewing them as regards material of all kinds. Perhaps F, but at any rate C bund should, I think, be restored for the reasons given above. But the length is only 300 feet across the channel required to restore the bund to what it originally was.

A considerable portion of L bunds having been carried away as before stated, suggests alone of itself the liability of the river's making a dead set successfully at any point along the bank, and, if persisted in, would eventually neutralize all the results of the closing of all the channels now fast silting up along the Nowrungah from A downwards. The chances are probably in favour of its not encroaching to that extent, but the set of the river is already on the end of M spur, and a "floating" or "weed spur" is being constructed to defend the high bank there. This may entail other "weed spurs," and this may in connection with the loss of L bund suggest the advisability of not continuing the cost of defence works for the future so far up river as at this point, that the river if left to itself so far up is not likely at all to encroach further than it has already done some time back, and that by limiting the operations more, instead of carrying them out so far up river, would give an additional advantage as regards economy and supervision. There will be considerable saving in expense in not having to renew all the bunds again from L to M with fresh material, also in having a good supply of múnj material and casks, &c., on hand already paid. On the other hand, I have only referred to the probable requirements on the south bank extending no further than the Nowrungah mouth. It is not improbable that the defence works may have to be carried up as far as L or even to E, by protecting the bank all along on the short "weed spur" principle above referred to.

I have submitted a separate "Memo." attached, showing the total expenditure incurred on different sub-heads of work since the commencement, viz., from January 1874, to 31st August, 1875. The Memo. includes cost of buildings, viz.:—

Temporary Bungalows, Observatory Tower, Worksheds and Godowns. I believe everything is included, &c., excepting some trifling stores indented for, for repairs to boats, casks, &c. The total and descriptions of the three kinds of work done, with cost, is as follows:—

Tree bunds, running feet, ...	36,162
Weed spurs, „	10,595
Net spurs (100 feet), ...	17,880
Total, ...	64,637

The total cost has been Rs. 3,17,176, or Rs. 4-14-6 per running foot of bund, "weed," or "net spur." The rate I before estimated at was Rs. 5 per lineal foot.

Rough Statement of Expenditure incurred on the Sutlej River-Training Works, from January 1874, *to* 31*st August*, 1875.

No.		RS.	A.	P.
3,243	Casks, at Rs. 4 each, ...	12,972	0	0
7,721	Nets and trongahs, at Rs. 10 each, ...	77,210	0	0
	Carried over, ..	90,182	0	0

No.			RS.	A.	P.
		Brought forward, ..	90,182	0	0
25	Wooden piles, at Rs. 20 each,	.. ..	500	0	0
1,890	Bullies, at Re. 1 each,	.. ..	1,890	0	0
mds.					
15,519	Rope, at Rs. 4-8-0 per md.,	.. ..	69,835	8	0
No.					
21,021	Trees, at Rs. 2 each,	.. ..	42,042	0	0
c. ft.					
2,35,055	Bricks, at Rs. 9 per 100,	.. ..	21,155	0	0 *
No.					
20	Wooden anchors, at Rs 20 each,	.. ..	400	0	0
9,500	Fascines, at Rs. 0-10-0 each,	.. ..	5,937	0	0
17,488	Bushes, at Rs. 0-8-0 each,	.. ..	8,744	0	0
	Labour,	.. ..	76,490	8	0
		Total Rupees, ..	3,17,176	0	0

The cost brought up to end of the flood season amounted to Rs. 3,25,000.

If at first sight the expenditure seems heavy, it should be explained here that more than one-third of the cost has been incurred on works of a tentative character, such as 100 feet nets, which, as applied, were not found to give any material benefit, and the cost of which would not have to be incurred again, and in estimating, however, future operations, the experience gained is advantageous.

It may be worth while to summarize the chief points of success attained since the commencement of operations in January 1874. They may be defined as follows, viz.,—defence of the river bank generally with more or less success by means of

I. *Weed Spurs and Fascines* at the following points:—

1st. Along north bank of river for a distance of more than a mile below the village of Lei-wahan.

2nd. Along same bank for about a mile above Ghotpoora.

3rd. Along sand bank at Adamwahan from old D spur to site of bridge.

4th. Along south bank for a distance of half a mile above "bridge site."

II. By means of "*Tree Bunds*," the results were the silting up of the following channels:—

1st. The Khanwah and Nowrungah channels extending from A to L bunds.

2nd. The silting up of the old channel scoured out in 1872 from under the high bank at Adamwahan, and the formation of "sand bank" at the same time for well sinking operations.

3rd. The growth and preservation of vegetation in river bed, such as willow, poplar, tamarisk, growth of which (if encouraged by the protection offered by the *Tree Bunds* holding out another season's floods) will by that time be sufficiently advanced as to afford in themselves considerable protection of a permanent character to the river banks.

I propose now to refer to some of the results of trials made with "*Fascines*" and with *Brushwood, Grass, &c.*

I. *Bushes of the wild caper, jhund, pillew, &c., or pilchi tied together in bundles and weighted with brick, or without any weight.*—For protecting the shore ends of the "Weed Spurs." It will be sufficient briefly to state, that when these were applied only at the "head" or "shore end" of the spurs, success was only very partial, the current getting behind too quickly: especially in strong water and in a sandy soil. Generally applied such brushwood after a short time would disappear altogether, and a fresh supply would be required.

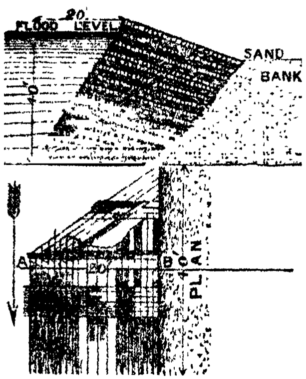
When made up into fascines and applied, they were most successful, even on this limited system.

II. "*Fascines*" *independently applied without any* "*Weed Spurs.*"—If applied continuously along a bank to be protected, "fascines" promise to be more successful than anything else yet tried, but they require trial on a scale sufficiently extended, so as to prevent any reasonable chance of the river's getting behind.

The brushwood (pilchi) is made up into fascines 10 feet long and 1 foot in diameter. Grass is put up into small bundles and tied together somewhat as in matting. There are different ways of applying the above.

1st. Laying down fascines for a bund, as a wall in a manner similar to the "drop" or "curtain wall" of a bridge, with or without flooring. This wall to consist of masses of fascines placed in layers crossing one another, tied together and placed all along the face of the sand bank to be protected.

A situation where this system would be applicable (and of importance, if successful in preventing the river's outflanking the bridge) is along the sand bank (south side) between the bridge and spur L. The distance across this sand bank on to the permanent bank is about one mile. The sand bank would have to be sloped sufficiently, so as to admit of the "fascines" being laid and built up into the wall as shown in the wood cut. The upper side is shown splayed off, so as to present as little resistance as possible to the river's action behind, and in case it be found necessary to use it only or at intervals in the form of "spurs," instead of continuously, as described further on.



There is a batter from base to top tending to throw the centre of gravity inwards towards the land, and so to counterbalance its tendency to tilt forwards, which would result from the under-scouring along the face of this "drop wall." As an additional security, the "mass" should be moored strongly to the bank, and allowed to sink a depth of from 20 to 40 feet, or in proportion to the depth of scour made.

The advantages of using such "material" as compared with stone would be, *1st*, as regards economy. Such material is always growing near at hand; *2nd*, a bank so defended continuously presents no projections. There would be, therefore, no obstruction offered to the river flowing smoothly by, as would be the case with "spurs," whilst the cost of "stone protections" to them, unless extended as far as the permanent bank, is liable to be outflanked and carried away by the river: when the loss would be incomparatively greater.

Its specific gravity is sufficient in itself to sink, but should additional weight be required, earth could be filled in, or brick tied up in nets added. It would last many years, and could be kept above flood level or not, as might be considered desirable, dependent on the amount of water required to be admitted to irrigate the trees and plants it would be proposed to grow over the land so reclaimed.

A similar plan could, of course, be applied across the low land on the Adamwahan side, should any unusual set of the river there make the plan to be thought necessary.

The second plan.—The second mode of applying the fascines (referred to above) is to have the wall only at intervals, say of a chain or so apart, or in fact as "spurs"; the sand bank in between the "spurs" being sloped and protected in front by two or three lengths of fascines, tied securely together like an apron, and allowed to fall down of themselves: willow and pilchi being sown in between the interstices left amongst the fascines.

Jungle grass.—Jungle grass tied in bundles and laid over large nets of "múnj rope" and used like matting, will probably also be found effective.

Third plan proposed.—There is a third plan to be proposed for defending the face of a long sand bank, viz., to put two or more lengths of "fascines" in one layer together, and to have them simply lying horizontally, tied together continuously along the top of the sand bank to be protected. With such a flooring, the action would be similar to that described above, viz., they would fall in like a curtain wall. As the edge of the sand bank cut away, however, the horizontal position of the "fascines" would be gradually changed to a "sloping one" as they became bent over, and dragged downwards, more fascines being then tied on. The extent of such protection would be as far as the permanent bank, or at any rate, so far as to prevent any likelihood of the river's outflanking the fascines, and the direction would gradually diverge like in the wings of a bridge.

E. B. M.

Note by M. Rayne, Esq., *Supdg. Engineer.*

The above Report has been drawn up by Mr. Medley, the Officer in Sub-divisional charge of the River Conservancy Works.

Mr. Medley very clearly describes the nature of the operations undertaken during the year, which operations he divides into three classes, chiefly with reference to the season at which they were executed, but they may be broadly described under two heads—

I. Works for training the river to a desired course.

II. Works for protecting the banks, where, in spite of the Training Works, the river has attacked or threatened them. From the map it will be seen that the river, during the season 1874-75, had a fairly good course, threatening at no point below Goodpoora. This course, or even a straighter one still, it pursued during the first great flood of the year. As soon, however, as this subsided, the river fell into the tortuous channel it now follows, shown Blue in the map.

The subsequent floods of the season, which were unusually heavy, caused considerable erosion at two points, Lei-wahan on the right, and again immediately above the bridge on the left bank.

At these places defensive works were undertaken, so far as the time and means permitted, but with these exceptions, the whole of the great expenditure, as stated by Mr. Medley, appears to have been incurred in a vain endeavour to train the river to a straight course, with the result that it is now more serpentine than ever.

The cause of these now oscillations, whatever it may have been, lay above the highest of our training works,—how far we do not know, but beyond where we can expect to follow.

I have already ventured to state my opinion, that events have shown that our operations may be less extended for the future than they have been for the last two seasons, and I recommended that henceforth they should be limited to the heads of the first great bunds above and below bridge; say to Lei-wahan, and a place about opposite on the Bahawalpur shore, for the above bridge limits. Those below are not of so much importance.

I would now tender a further suggestion, that the character of the works be altered to some extent, at any rate wherever they are so placed, as to make their action of an immediately defensive nature.

Beyond some lines of trees, placed across the low lands chiefly on the Bahawalpur side, for the purpose of encouraging a deposit of silt, but little has been done save to put down "weed spurs" as they are called. These have not been of the inexpensive type their designer, Col. Brownlow, gave them, nor have they perhaps always been put down in the way he intended. It may be in consequence of this that they have hardly fulfilled expectations. Certainly the system has been pursued at a cost it is hardly likely will be long continued, having regard to the general results already described.

I am far from saying that there are no occasions in which the "weeds" may be advantageously used, but to depend wholly upon them seems to me futile, from the mere fact that while they themselves have no permanence, their work even when successfully done, is not more lasting. What the river deposits so readily, it as readily takes away when it chooses, and the agency which caused the deposit is no longer in existence to defend it.

Large trees with their roots and full heads, make a very good and tolerably lasting defence; but these are not to be had, nor even small trees, nor brushwood within an easy distance. The country has in fact been denuded in the neighbourhood of the bridge works.

This being the case, I would recommend a return to the system followed in 1872, in protecting the colony just above bridge, that of making platforms of fascines, sinking them with earth, rebuilding upon that with repeated similar layers till the mass sinks no more, and the tops remain above water.

These spurs last a long time under water, and if made of fascines well put together, and the whole moored securely to the shore, are not easily carried away.

The fascines may be made of materials, still, and I believe always obtainable, pilchi of the low tamarisk which springs up all over the flooded lands.

I would protect the right bank from Lei-wahan downwards, with a series of short spurs such as above described, and the same on the opposite side from spur L down to the bridge.

I do not think any more work is needed on the left bank above L, unless it be about F for the purpose of throwing river over to the Adamwahan side, when the time comes. For this work the weed spurs may be properly used.

I do not apprehend danger to the bridge from the left bank except from sudden attacks near to it, such as that made towards the close of this season's floods. To guard against these, I hope that stone will be largely used hereafter.

I believe the most danger to be on the other side from the apparent fact that the river is travelling, and has for many years been travelling towards that side. No doubt it often attacks the left bank in our neighbourhood also, but only to remove some low land deposited by it the other day; while the destruction it commits on the opposite shore to which it speedily returns, is all upon pucka land forming the permanent bank.

It will be observed that Mr. Medley has adopted a suggestion formerly made by me, to afforest a large extent of land on both sides of the river above and below bridge. I trust this suggestion may be deemed worthy of consideration. My idea is, that though the roots of no trees can penetrate deeply enough to prevent undercutting, yet that when undercut and before falling into the river—if they were secured to others still standing behind them, and those to others still further back; there would shortly be found a mass of dèbris, affording at least as good a protection as anything that could be made artificially—probably a very much better—since the trees used in artificial tree spurs never have their roots, and are always limited in size by the difficulties of carriage.

Fifteen or twenty years seems a long time to have to wait for this natural protection, but the banks of the river must be preserved for all time, naturally or artificially, and in either case the trees must be grown somewhere to do it withal.

On recently discussing the subject with the Political Agent and Superintendent, Bahawalpur State, Col. Minchin and the State Forest Officer, Mr. Calthrop, I found both very favourable to the scheme, so far as regards their side of the river. Col. Minchin offered the whole of the land required free; and Mr. Calthrop offered his services in promoting the undertaking in any way he could. He has begun some large plantations in various parts of the State, one near Báján-ki-Gote, on very similar land to that available for our purposes, and where the young trees are coming on remarkably well, promising to be efficient in the way I have described in 12 or 15 years at most.

While examining the flooded lands on the banks of the Chenab with Col. Minchin the other day, we came to a fine piece of natural forest of Euphrates poplar and babúl, of which a large slice had been carried away by the river this season. The practice had been to cut down and remove the trees as fast as the river encroached, but I suggested to Col. Minchin a trial of lashing them back to those further inland and allowing them to fall bodily into the river. He at once gave orders for this to be done, and though the trees are too young and small for a fair experiment, it is still one that will be watched with interest.

To conclude, I would propose to take up for forest the whole of the land on the Bahawalpur side of the Sutlej, from spur A above bridge to any convenient distance below bridge, the further the better, since for several miles the river is not too far away from the line of railway, for safety.

On the Adamwahan side I would take up land from the head of the Goodpoora Dhund, down to a distance of 3 or 4 miles below bridge on both sides to an average width of 3 or 4 miles. The Bahawalpur land will cost nothing, and is irrigable from the new Nowrungah and Khanwah Canals. The land on the right bank will for the most part have to be bought, as it is almost entirely bangur and cultivated. It may also be easily watered by restoring one of the old canals.

I will not enter on the question of the expense of these plantations, because the creation of forests is not a work fairly chargeable to the bridge or the railway, any more than Chunga Munga plantation is a charge to the Scinde, Punjab and Delhi Railway. As I have said, the country is so bare of trees, that plantations must be made somewhere, and they can be made at least as cheaply and as well where I have indicated, as elsewhere.

M. R.

Note by COL. F. W. PEILE, R.E., *Engineer-in-Chief, on the operations of the year* 1875, *with proposals for the future.*

Mooltan, January 31st, 1876.

A good measure of success appeared to have attended the operations of the early part of last dry season. In March, the bridge site lay towards the end of a straight reach some 5 miles in length, the channel occupying nearly the centre of the bridge opening. This favourable state of things was produced partly, no doubt by the training works, but there seems now to be reason to believe, that nature had a large share in it. At any given place in the river, periods of oscillation and directness of course, alternate; whether induced by the causes originally suggested by me, or by some other natural causes, is immaterial. The period of direct flow in the reach under notice had apparently arrived, and aided by the training works, what was reported to be considerable success, was attained.

It was supposed if such a straight channel could be engendered during the dry season that the inundation water acquiring at first a certain direction from the patent channel, would continue to flow somewhat steadfastly in the direct course, and that thus a series of temporary, and as it was assumed, inexpensive measures, carried on in the dry season, would suffice to guide the river during the inundation through the bridge opening, and prevent such wanderings of the stream as might threaten to outflank the bridge.

The effect of the floods of last season leave little room to hope that such gentle measures will produce the results anticipated, and the measures themselves, instead of being economical or of small cost, have proved to be very expensive indeed, and threaten by exhausting the available supply of material to become yet more so.

The Reports submitted by Mr. Medley, the Exec. Engineer in immediate charge of the Training Works, and by Mr. Rayne, the Supdg. Engineer, describe somewhat in detail what has been done, and how, when the heavy floods of the latter season occurred, the various appliances deposited in the river to influence the currents were carried away, and that the present course of the river near the bridge has become in fact more sinuous and threatening than when the training operations were first commenced.

From Mr. Medley's Report, it appears that in two seasons commencing January 1874, a sum of Rs. 3,25,000 has been spent on these works, and on the provision of material for the coming season, to utilize which a further sum of Rs. 50,000 would have to be spent. The expenditure may, therefore, be put at Rs. 1,25,000 for each season. This, however, does not afford a fair gauge of the future. The neighbourhood for several miles has already been denuded of trees, and those now procurable are unsuitable from their size, independently of the high price at which they must be used in the work.

The whole subject has, for the past two months, been anxiously considered, and discussed by the Supdg. Engineer and myself, and at a meeting at Adamwahan on the 12th instant, at which we had the advantage of Mr. Galwey's (Exec. Engineer recently joined) assistance, I was able to decide on the nature of the Report and recommendations to be submitted to Government.

During the past season, the river rose four times in flood; on the first occasion during its rise, the stream followed the tolerably straight course prepared for it, but on subsiding, it fell into sinuosities which became more devious during subsequent floods. The main stream shifted towards the south, and flowed through the second span from the Bahawalpur side, directing its violence principally on pier P, the second from the abutment at that end. The wells of this pier were resting on a bed of clay encountered at a depth of 30 feet, and had penetrated into the clay but four or five feet; they were surrounded by a heavy protection of stone, to which additions were made from time to time, until over 1,00,000 cubic feet had been thrown in. The cylinders were not disturbed in the least.

As the river fell after the last flood, it continued to cut into the high bank at Lei-wahan, whence it was deflected towards the south abutment of the bridge. The last elbow formed above the bridge site now projects considerably to the rear of the abutment, and the stream continues to sweep round the mass of stone laid in the abutment span, and to pass through the opening P, Q.

The floods of the season were higher than any of which we have a record. The Adamwahan colony was submerged, and the whole country to the south of the river was under water as far as the eye could reach; the only dry spot being the railway embankment on which were congregated all the inhabitants of the neighbouring villages with their cattle and household effects. I am informed that the water was found to be headed up to the extent of three feet nine inches on the upperside of the embankment, at a distance of about half a mile from the bridge opening, and probably there was a greater difference of level above and below the embankment at, and about, the old Nowrungahwah channel, which was the only opening left in the embankment. The railway bank finally yielded to the pressure, and several large breaches occurred, and subsequently holes 20 feet deep were scoured out. This indicates a source of danger in the future. The inundation water will be penned up in the recess formed between the railway embankment and the high bank of the river, and unless special measures be adopted, will certainly force its way through.

The old channel of the Nowrungahwah has been abandoned, and the opening in the embankment at this point has now to be closed. A new alignment has been given to the combined Khanwah and Nowrungahwah canals (*see* map), and the new channel passes the railway within the high ground near the Bahawalpur station.

A carriage road from the city of Bahawalpur to the ferry crosses the line of railway. This road was carried on an embankment some three or four feet high, and was seriously breached this year: the Political Agent proposes to increase its height, and to meet the railway bank on a level crossing.

There are two dangers against which we must guard ourselves—

I. The breaching of the embankment by the headed up inundation water.

II. The incursions of the deep stream which advances by scouring and undercutting.

At the recent meeting at Adamwahan, above referred to, the following opinions were recorded :—

PRESENT:

COLONEL F. W. PEILE, R.E., *Engineer-in-Chief.*	MR. M. RAYNE, *Superintending Engineer.*

MR. W. J. GALWEY, *Exec. Engineer.*

"(*a*). We are of opinion that the temporary training works, such as bushes, "weeds, nets, and so on, useful enough in leading the cold weather channel, are "quite inoperative in determining the course of the large channel, during inundations; "and that if they are not entirely swept away, they are likely to aggravate the action "they are intended to oppose—this has been the result of the experience of the past "season."

"(*b*). We are also agreed that some obstruction of a solid permanent character "must be opposed to the river's cutting into the deep bay above the bridge on the "Bahawalpur side."

"(*c*). Mr. Rayne is of opinion that not only the river channel but the inundation "water also should be excluded from the angle between the railway embankment "and the high bank of the river. Last season there was a difference of water level "of three feet nine inches on the upper and lower sides of the embankment at half a "mile from the bridge abutment; the embankment gave way, though not overtopped, "and large scour holes 20 feet deep were formed. He would, therefore, interpose an "earthen embankment from the bridge abutment to the permanent high bank of the "river protected in front by stone."

"(*d*). Mr. Galwey thinks that the admission of the inundation water would tend "to raise the level of the whole area by deposition of silt, and he would leave large "gaps for the passage of the water through an embankment, in other respects similar "to Mr. Rayne's.

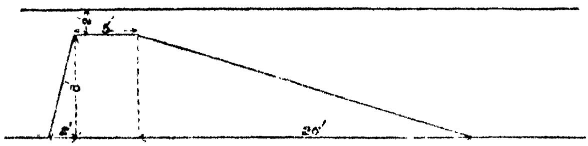
"(*e*). Colonel Peile agrees with Mr. Galwey in the opinion that to admit the "inundation water would be advantageous, but thinks it would be preferable to allow "it free ingress over the surface, and not force it through openings in an embank- "ment, he, therefore, would omit the earthen embankment, and limit the work to a "mass of stone, through or over which the water would enter.

"(*f*). We also agree that protection of a similar character is required to the right "bank."

Measures may be taken to afford reasonable security against the first source of danger indicated above No. I. The railway embankment from the bridge up to the high bank of the river, and the state road may be raised to at least five feet above the highest flood; the up-stream slope of the railway embankment can be formed of clayey soil, which can be obtained by excavating to a depth of six or eight feet on either side. This soil, if carefully laid and well punned will be impervious to water. The slope should be extended to a base of 5 to 1 in height, and should be thickly grown with grass and tamarisk. These measures will probably suffice to resist the action of the inundation water, which, if freely admitted, will, in the process of time, raise the level of the surface of the bay by the deposition of silt, until eventually the water should not be able to enter at all. It would be necessary to prevent the off-flow of the water along the embankment by a few spurs near the bridge, and the whole area as suggested by Mr. Rayne, should be planted out with trees.

To resist the second danger noted above, No. II., viz., the incursions of the main stream, is a more difficult matter; the very tortuous channel of 1872-73 shows that we have reason to apprehend future attacks at a distance of a mile or more from the bridge head, and I am decidedly of opinion that the only effectual means of opposing such attacks is the interposition of a strongly constructed line of defence extending from the bridge head to the high bank of the river.

I am disposed now to modify the form of embankment originally proposed. I would omit the earthen embankment with the advanced protection of trees, and simply deposit a quantity of stone in a trench cut down to the low water level. As the undercutting scour in the main stream



extends to a depth of 30 feet; it may be assumed that a surface measuring 42 feet on the slope, with the base equal to the perpendicular, must be covered with stone to a thickness of three feet to afford sufficient protection; in other words that for each lineal foot about 120 cubic feet of stone should be provided. This quantity, or preferably 150 cubic feet I would dispose in a stack of the cross section shown in the woodcut; a trench being excavated for its reception where necessary. If the river developed any tendency to cutting in the deep bay near site, the line of protection would be extended towards W.

Rough stone from Chunneote is at present delivered at the bridge for Rs. 26 per 100 cubic feet, and the cost of this protective work would, therefore, be about Rs. 40 per lineal foot for stone only. When, however, the line can be opened to Sukkur, a large reduction may be made in the cost of stone. Assuming that it may be quarried for Rs. 2, and hauled the 220 miles at three pie per ton mile, as has been proved to be possible on our metre gauge tramways, the cost would be Rs. 20 per 100 cubic feet of stone, and the protective work would be constructed at Rs. 30 per lineal foot.

The line is 12,500 feet in length, and the cost of the work would therefore be

	Rs.
12,500 lineal feet stone, at Rs. 30, ...	3,75,000
12,500 lineal feet excavating, &c., at Rs. 2, ...	25,000
Total, ...	4,00,000

As, however, the work would have at least to be commenced with stone procured at the higher price from Chunneote, it would be proper to estimate the total cost at Rs. 5,00,000.

Protection of similar character will, I consider be required on the Adamwahan side; the Sutlej, in common with all the Punjab rivers, works towards the north west, and year by year encroachments are made on the high right bank. Close to, and above the bridge, the bank is at present fairly protected by the masses of fascine work put in during 1871-72 and 1872-73, but there is reason to apprehend danger from erosion at Goodpoora and Lei-wahan, and I think we must be prepared to oppose any such encroachment by a protection laid along the line A, V, T. At present I would confine this work to the portion A, V, about 4,000 lineal feet, and to a length of 1,000 feet below bridge, all of which should be executed with Chunneote stone laid on the bank, sloped back to a base of 2 to 1 height, the cost of this portion would be

	Rs.
5,000 lineal feet stone, at Rs. 40, ...	2,00,000
5,000 lineal feet bank sloped, at Rs. 4, ...	20,000
Total, ...	2,20,000

Any extension of the work required hereafter should be in the direction indicated towards T, the stone being laid in a trench in manner similar to that proposed for the Bahawalpur side.

I think that the tree spurs M, F and E, constructed during the two past seasons, should be maintained, in order to resist any tendency of the main stream to enter the large bay above new Meeani, and that the whole of this area, together with the bay between Goodpoora and Lei-wahan, should be thickly planted with forest trees, as proposed by Mr. Rayne.

In regard to the order of executing the work, it being impossible to complete the whole in one season, I would propose first to add temporarily to the protection of the Bahawalpur abutment, by laying down a mass of stone on the up-stream berm of the embankment; I have already ordered, that a reserve of 2,00,000 cubic feet of stone shall be laid down at once in this position in a stack 2,000 feet long, with a cross section of 100 superficial feet. This stone would eventually be moved forward on the advanced line of protection. The protective work itself should be commenced at the high bank of the river, and be projected forward until it reaches the bridge, striking pier Q, the first pier from the abutment, so that the abutment span may fall entirely within the line of protection.

I consider it would be unsafe to begin at the bridge end, as the work might be outflanked by the river before the line could be completed, and aggravate the danger it is desired to resist.

On the Adamwahan side no immediate danger threatens. There will probably be a surplus of stone above that required for the bridge foundations undertaken this season, and it will be stored along the top of the high right bank above bridge.

I am opposed to undertaking any more measures for leading or driving the stream during this cold season; the channel, though tortuous now, occupies a position peculiarly convenient for the bridge works; it passes through the second span from the Bahawalpur end, and thus the whole of the new work of the season is directly accessible by tramway from the Adamwahan side. Any interference up-stream with the river's course might drive it on to the works and cause much trouble. On the other hand, as has been shown, temporary coercion of the stream; at this season, cannot be expected to survive the action of a flood, and I regard expenditure in this direction as so much money thrown away.

F. W. P.

No. CCXXIX.

HYDRAULIC EXPERIMENTS AT ROORKEE, 1875-76.

BY CAPT. ALLAN CUNNINGHAM, R.E., *Hon. Fell. of King's Coll., Lon.*

ABSTRACT AD-INTERIM REPORT ON ABOVE.

References to printed Report of 1874-75.

[N.B.—These Results refer only to a rectangular section as in the Solani Aqueduct.]

1. THE former conclusion that the motion of water is technically "unsteady" is fully confirmed. (Art. 25 of last Report.)

2. The use of "Twin Balls" for sub-surface velocity-measurement requires the simultaneous observation of surface-velocity *over the same line.* Near the margin surface-floats move so irregularly, that it is impossible to satisfy this condition tolerably in this position. (Art. 50 of last Report.)

The "Twin Balls" are, therefore, useless for work near the margins.

3. Metal balls were introduced instead of wooden ones, and metal tubes instead of the wooden rods, and have been found to be free from the grave inconveniences of wood, and cheaper in the end. (Art. 43, 67 of last Report.) (Art. 71 of last Report.)

4. At, and near, the centre, the mean velocity in a vertical plane, found by measuring velocities at every foot downwards with the "Single Ball," is now found to be nearly the same as the mid-depth velocity as measured by the same instrument, and also nearly the same as the velocity of a "Rod" reaching nearly to the bottom. (Compare Art. 40, 62, 72, of last Report.)

5. The line of maximum velocity is usually below the surface; it is highest at the centre, and gradually sinks towards the margin, being at about mid-depth near the margins.

6. The mid-depth velocity therefore differs from the mean velocity of a vertical plane by an amount increasing towards the margins, where it becomes actually the maximum.

[It cannot, therefore, be adopted as a measure of the mean velocity of a vertical plane, as proposed in America, except near the centre.]

7. The mean velocity in a vertical plane, found by measuring velocities at every foot of depth with the "Single Ball" is liable to a certain error due to the surface action on the attached surface-float. It is now found that the velocity of a "Rod" reaching nearly to the bottom, differs from the former measure of mean velocity constantly in such a direction as to be probably free from that error.

(Art. 43 of last Report.)

The velocity of a "Rod" reaching nearly to the bottom is, therefore, probably as true a measure of the mean velocity through its plane of motion as can be obtained in any other way.

On account of its handiness, cheapness, &c., it is, therefore, perhaps the most convenient instrument for measuring the mean velocity along a vertical plane, in moderate depths, say not greater than 12 feet.

[Should this be further confirmed, it will be a discovery of great importance, as a good measure of "Discharge" could then be obtained by its use with fair rapidity].

N.B.—The questions in paras. 4, 6, 7 above, were those suggested in last Report, (Art. 78,) as most worthy of investigation.

8. The measurement of surface slope found to be a very delicate observation, too delicate for ordinary use.

9. Surface slope increases with decrease of depth at same section, whether the canal be rising, stationary, or falling.

[This result is so extraordinary as to require further investigation].

10. The mean velocity of a whole section is not simply proportional to $\sqrt{RS}$, but if we assume $u = C\sqrt{RS}$, C must be a factor increasing with R.

[Bazin's factor $1 \div \left(\alpha + \frac{\beta}{R}\right)$ is one of this kind: this is a partial confirmation of his formula].

11. The mean velocity curve is found to be very flat indeed across the greater part of the channel, there being no marked diminution of the

mean velocity (in a vertical plane) over about $\frac{3}{8}$ of the width of the rectangular channel: the diminution even close to the margin (of the rectangular section) is only about $\frac{1}{6}$ of the mean velocity in the central vertical plane; on the other hand in a trapezoidal channel, the diminution of the mean velocity is very great near the margin (*i. e.*, over the sloping sides), amounting sometimes to $\frac{2}{3}$ of the central mean velocity.

This shows that the mean velocity in a vertical plane depends in an important manner on the depth.

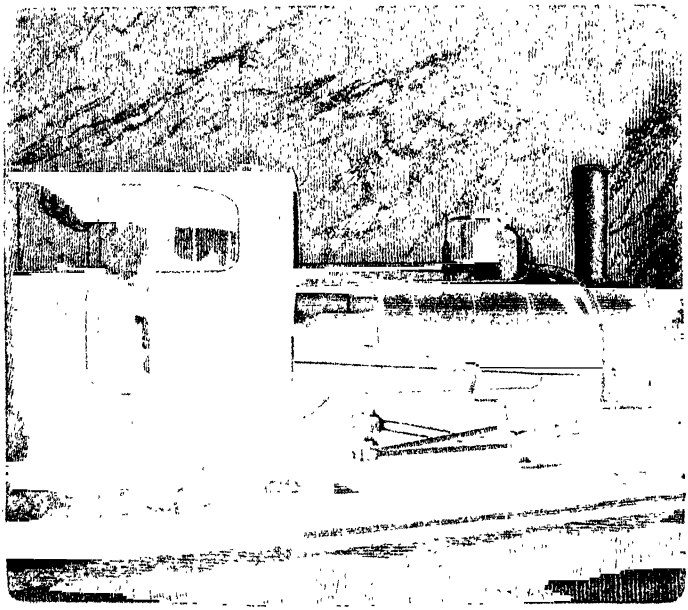
No. CCXXX.

THE NEW RIGI COG-WHEEL LOCOMOTIVE.

[*Vide* Frontispiece and Plate XXIX.]

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

Monsieur Riggenbach—the able inventor of the rack-rail system of mountain railroads—having abandoned the vertical boiler which was so distinguishing a feature of his locomotives, now employs locomotives whose boilers are perfectly horizontal on a gradient of 1 in 10. We illustrate on a large scale one of these locomotives in *Plate* XXIX; the Frontispiece and sketch will also be interesting.



The engine is of 160 H. P. It weighs when ready for work 17 tons, and usually drags a train load of 13 tons up a gradient of 1 in 5, at a speed of 5 miles per hour. On special occasions it has dragged up a gradient of 1 in 6 a train load, equal to the weight of the engine, of 17 tons, at a speed of 7½ miles per hour. The boiler capacity is 60 cubic feet, and that of the water tank 53 cubic feet. The bunker holds half a ton of coals. The square feet of heating surface in the boiler is 44½, and the fire grate surface is 10¾ square feet. The boiler pressure amounts to 147 lbs. on the square inch. The crank and driving axle, in connection with the cog-wheel fittings, work the driving cog-wheel into the rack-rail, and hence produce motion. In this way the locomotive power of the engine is increased two-and-a-half fold. The driving cog-wheel has a diameter of 3·46 feet, a circumference of 10·824 feet, and 33 teeth. It is made from the finest steel cast in one piece, the teeth being accurately cut out after casting. They stand nearly 4 inches apart from centre to centre; ten teeth occupying one metre (3·28 feet) of the rack-rail. The driving cog-wheel usually makes 40·4 revolutions per minute.

The brake mechanism of the locomotive is three fold. (i). The crank-axle-brake worked by the engine driver, which, when put in action, holds the driving cog-wheel firmly, and prevents its turning and so engaging in the rack. (ii). The similar forward axle-brake, which is worked by the stoker. (iii). The air-brake which, by means of compressed air in the cylinders, works through the rods and fittings directly on the cog-wheel.

Engineering, Vol. XXIII., contains, at page 165, figured drawings and detailed description of a larger rack-rail locomotive used on the Kahlenberg line.

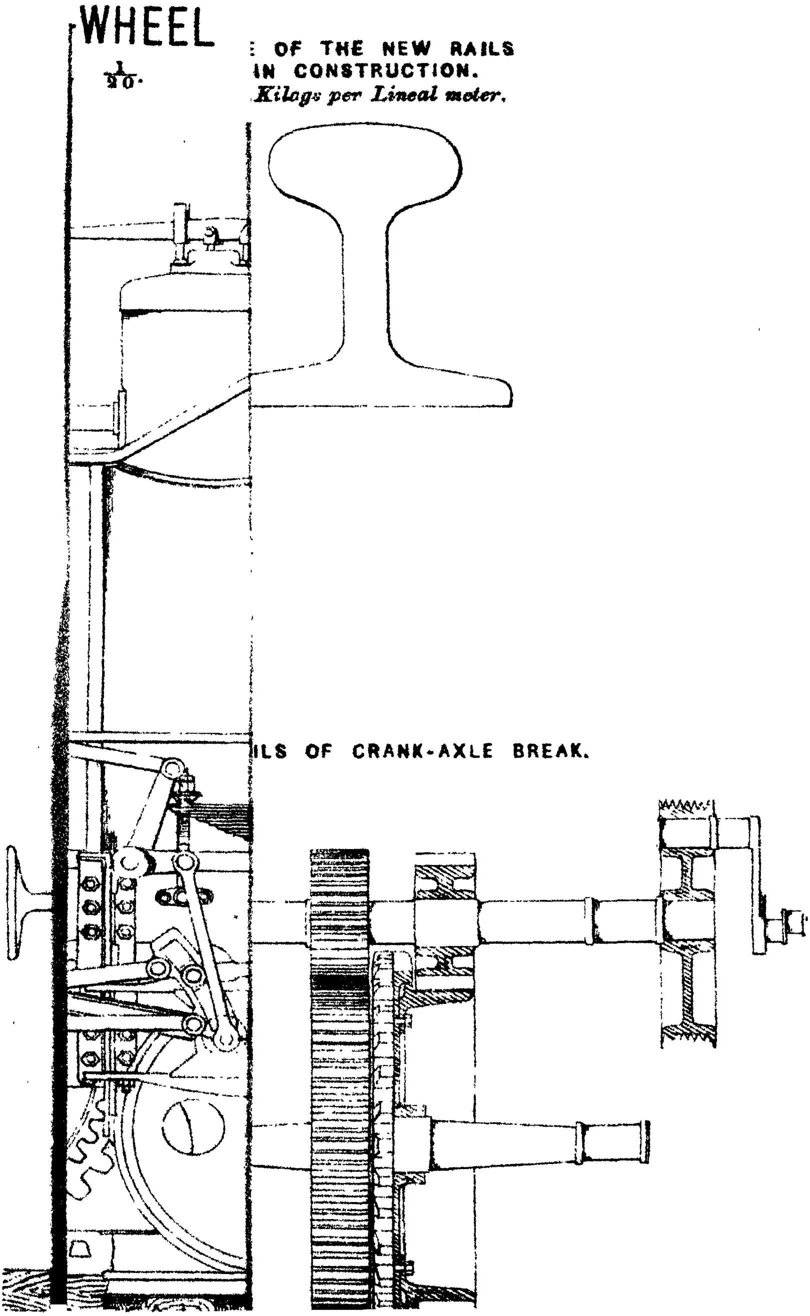
It may be useful here to add a brief statement of the present position of the rack-rail system of Mountain Railways.

There are now 8 Rack-Railways on the Continent, either working or in process of construction.

On these, 32 rack-rail locomotives are in use, as follows:—

On the Witznaw Rigi line, (Switzerland,)	10
Kahlenberg line, (Vienna,)	
Schwabenberg line, (Pesth,) ..	
Arth-Rigi line, (Switzerland,) ..	
Rorschack-Heiden line, (Switzerland,)	
Ostermundingen line, (Switzerland,)	
Wasseralfingen line, (Germany,) ..	
Rüti line, (Switzerland,)	
Total,	32

* Of the type above illustrated.


WHEEL
1/20
: OF THE NEW RAILS
IN CONSTRUCTION.
Kilogs per Lineal meter.
ILS OF CRANK-AXLE BREAK.

Nine types of the rack-rail locomotive have been constructed by Mons. Riggenbach at his special workshops at Aarau. According to the construction of the lines and the loads to be dealt with, these locomotives vary in weight from 10 to 30 tons, while the power they are capable of developing varies from 80 to 400 horse power. The smallest rack-rail locomotive yet made is capable of taking a load of 25 tons up a gradient of 1 in 10; and the largest yet designed, for use on main lines, will take a train of 120 tons at a speed of 6 miles an hour up a gradient of 1 in 20. In the engines for main line traffic, the arrangement is such, that, when a steep gradient is being ascended by the aid of the rack-rail, the ordinary driving wheels become carrying wheels only; while on the other hand, when the engine is being used as an ordinary locomotive, the rack-rail gear does not work.

The Government of Baden have ordered the survey of a line on the rack-rail system from Fribourg to Neustadt and to Donaueschingen in the Black Forest, with gradients of 1 in 20, and 1 in 16½. The Italian and Swiss Governments have just sanctioned the construction of a trunk line on this system 108 miles long. It will pass from Lake Lucerne on the Swiss, over the Alpine Pass of St. Gotthard, to Lake Como on the Italian side, and will connect the following towns :—Immeusee, Schwyz, Altorf, Biasca, Lugano, Chiasso and Como.

"Altogether the rack-rail system has many points in its favor, and "we regard it as pecidedly preferable in every respect to Mr. Fell's sys-"tem of centre rail with horizontal gripping wheels. That its employ-"ment will become considerably extended cannot be doubted." (Engineering, June 1st, 1877, page 413).

J. L. L. M.

No. CCXXXI.

MOUNTAIN RAILWAY FOR THE NILGIRI HILLS.
(2ND PAPER).

BY CAPT. J. L. L. MORANT, R.E., *District Engineer, Nilgiris.*

[THE subject of "Mountain Railways" has been discussed in the Professional Papers on Indian Engineering in two Articles, one (No. CLXV., July 1875) dealing directly with the question of a railway to the Nilgiri Hills, *viâ* the Coonoor Ghaut, the second (No. CLXXXVI., January 1876) relating to the Central Ladder system, as already employed in Switzerland and Austria. The subject is one which must ere long come before Indian Engineers in a practical form, as the net work of main lines of railway over the plains of India approaches completion, and attention and money can be spared for connecting this system with our Military posts, our stations, and our colonies in the Himalayas, Nilgiris, and other mountain ranges: meanwhile, it is of advantage to collect and analyse all the information which the spread of the several Mountain Railway systems in other countries renders available to students of this special branch of engineering science. The readers of this publication are indebted to Captain Morant, R.E., for careful investigations into the working of European lines, and for able reports and compilations, both in regard to the proposed line over the Coonoor coast, and with respect to the general question of different systems of Mountain Railways. Although the Government of India are not at present prepared to sanction at the expense of the State the railway above referred to, it is possible that private enterprise may raise the requisite funds; and the question continues to occupy the attention of the local officers. Captain Morant deeming that the reluctance of Government to undertake the railway in question was due in part to the want of complete information in regard to the cost and details of working of the several systems, has continued to collect further data, and to correspond with the most eminent pioneers of mountain railway construction in Europe.

The following extracts from reports and letters, &c., from this officer's pen, will be found interesting and instructive, and will make the reader *au courant* with the latest progress achieved in the Rigi system of railways.—Ed.]

In paragraph 2 of Public Works Department G. O., No. 1213 of the 30th of April last, occurs this paragraph:—"The actual cost of construction and maintenance of the Fell system seems to be but imperfectly known, and that of the Rigi system to have been unduly enhanced by the shortness of the lines on which it has hitherto been carried out." This appears to imply that more accurate information regarding these two systems is desirable, and I am informed that such further information has been asked for by the Government of India. I took the liberty of sending the above G. O. to Mons. Riggenbach, the Inventor of the Rigi system and Director of Mountain Railways in Switzerland, with whom I had been corresponding, and he has most readily and courteously, through his colleague Colonel Zschokke, supplied me with a considerable amount of reliable information regarding both the above systems, particularly that of the Rigi, which I trust Government will be pleased to consider of sufficient importance to be recorded in print, either for present or future reference. I believe the Secretary of State for India has declined at this present moment to sanction any railway to these hills. But since the desirability of such an undertaking will in a few more years be probably placed beyond question, I hope Government will consider that all reliable information which can in the meantime be collected is of importance. I have therefore the honour to append Colonel Zschokke's letter, and a survey plan of the Rigi mountain, as also translations from the German and French of two pamphlets relating thereto.* I have gone to some trouble to convert all German and French measures, weights, and money into their English equivalents, so that the whole subject may be more easily understood.

* *Vide* Professional Papers on Indian Engineering, Second Series Vol. V., page 1

It has been by many supposed that the Rigi system could only meet a large passenger traffic, but it is now proposed for an annual grain traffic of nearly 4,50,000 tons, or a daily traffic of from 1,500 to 2,000 tons. To carry this traffic, it is to be laid on a gradient of 1 in 12½, this being the same gradient on which Fell's system has been laid in Brazil. But whereas Fell's engine has only been able to drag 27 tons, the Rigi engine is calculated to push up 60 tons of paying load on this gradient.

With regard to Colonel Zschokke's *critique* on the Coonoor Ghaut estimates, there does not (when the figures are examined) appear any serious difference between his estimates and those made by Major A. deCourcy Scott, R.E., at least so far as the rack-rail system is concerned. The cost per mile of M. Riggenbach's railway from the table in paragraph 25 of Major Scott's report, after correcting a slight error in addition, is put down at .. .. Rs. 1,85,087

Colonel Zschokke's estimate is .. .. ,, 1,94,387

Difference Rs. 9,300

or about 5 per cent. But the latter's charge for rolling stock, which is per mile Rs. 13,400 over that in Major Scott's report, is calculated for a traffic of 21,000 tons per month, or twelve times the estimated traffic on the Coonoor Ghaut. There is a larger difference in the respective estimates for the Fell Railway, as follows:—

Colonel Zschokke's estimate, ...	Rs.	1,96,114
Major Scott's estimate (corrected in addition),	,,	1,59,714
Difference	Rs.	36,400

But the excess in the rolling stock accounts for Rs. 15,000, and for the rest Colonel Zschokke's figures are probably more correct than Major Scott's. No one, I presume, will now dispute that the Rigi system on the Coonoor Ghaut will be cheaper than Fell's system. Major Scott makes the difference in his corrected figures £65,696, Colonel Zschokke makes it £1,05,222.

With regard to the estimate for maintenance, it would seem that Major Scott's figures are not likely to be exceeded. The annual working expenses of the Rigi line were £9,519 in 1874. But all expenses of management and train service are, it is to be supposed, greater for passengers than for goods traffic, and will thus be proportionately less on the Coonoor Ghaut, where it is chiefly goods traffic which has to be provided for. The train mileage compares—Coonoor Ghaut 17,000, Rigi 20,988. The entire annual working expenses on the Rigi (a single line) on a gradient of 1 in 5, are 9*s.* 9*d.* per train mile. Over the Arlberg (a double line), with a gradient of 1 in 12½, they are calculated at 6*s.* 6*d.* per train mile; but the cost of the traffic service (such as wages of ticket-collectors, porters, &c.,) seems to be omitted. The Arlberg Railway is so very different in its construction from what a similar system on the Coonoor Ghaut would be, that it is difficult to compare the two. The galleries and tunnels on the former would not be required on the latter, and there is the single line against the double. The rolling stock on the Swiss line is also far greater than would be needed on the Coonoor Ghaut.*

In paragraph 3 of Public Works G. O., No. 484 of the 19th February, 1875, allusion is made to Mr. Handyside's method of surmounting steep gradients by a combination of the locomotive with the stationary engine. As a locomotive on this principle was exhibited only the other day at this year's annual meeting of the British Association at Bristol, I trust I may be allowed to quote what an able engineering writer of repute says of it:—

"Mr. Handyside's paper describing his patent locomotive, and his proposals as to the system of construction to be adopted in the railways of the future, led to a somewhat warm discussion. Like most inventors, Mr. Handyside was unfortunately disposed to ride his hobby to death. Instead of advocating the use of his system under very special conditions, he seemed to argue that all railways should be made in *steps*, long stretches of level alternating with short inclines of 1 in 10. It is hardly necessary to say that such a scheme did not find favour with the Engineers

* Messieurs Riggenbach and Zschokke have proposed to apply their rack-rail system to the wire rope and stationary engine class of mountain railway. In the ordinary railroads of this class, the weight to be removed exerts a direct pull on the rope, requiring a maximum strength in all the moving parts of the machinery; in the method employed by Riggenbach and Zschokke, a drum, furnished with a toothed wheel working into a rack laid between the rails, is attached to each carriage, and round it works the traction rope. This rope is carried round pulleys with a diameter sufficiently large to obviate damage, drums being dispensed with. The rack movement enables the train to be brought up at almost any point; and through the absorption by the rack of a great portion of the dead weight of the train, the driving rope can be slighter and more pliable. The difference between this and the Rigi system lies in the rack, which in the former case is laid on the ground, whilst in the latter it is carried by two bearers each 7 inches thick. In the middle of the track at about 29·5 feet apart are two rollers to guide the rope; while at each end of the line are drums 9·8 feet in diameter, the upper one moved by water or steam. The rotation of the drums at the head of the incline imparts motion to the endless rope which moves the two driving discs of the driving cars, one of which is attached to each ascending and descending train. The driving car consists of a frame resting upon two axles, carrying a toothed wheel connected with the driving discs, and griping in the rack. The brakes are effectively worked from the platform of the car. *Proc. Inst. C.E., Vol. XLI.*, (1875,) *page* 275.

present, Mr. Brunlees in particular handling it very roughly. The locomotive* was to have been seen at work at the Avonmouth Docks on Monday during a visit which a large party made to the works by special train. Unfortunately, however, a plummer block cover connected with the winding gear had broken, so that the special feature of Mr. Handyside's engine and the working of his system could not be seen. The engine was taken up and down an incline of 1 in 12, and the strut lever (the lower end of which grips the rail with a kind of Fowler's clip arrangement) proved itself a most efficient brake as might have been expected; it entirely prevented backward motion of the engine and a heavy coal truck upon the incline mentioned. More than this, however, the trials did not show. From what we heard of the working of the wire-rope arrangement during the few days for which it had been used, we think it possible that in some few cases it may be of use. These cases would probably occur chiefly on works where otherwise a stationary engine as well as a locomotive would have to be employed, but much more lengthened experience is required before it is possible to say how far the system is suitable even for this purpose. The wearing of the rope (which has of course no pulleys to run upon) and of the rails under the strut brake are serious questions which time will answer. There does not seem any reason for thinking that the plan is adapted for general use."†

Letter from COLONEL O. ZSCHOKKE, *Chief Engineer of the International Company for Mountain Railways in Aarau, to* CAPTAIN J. L. L. MORANT, R.E., *District Engineer, Nilgiris.*

We are in receipt of your letters of the 2nd and 24th of May respectvely, with the two orders of the Madras Government, dated respectively the 1st and 30th of April, 1875. With reference to the letter of M. Riggenbach, in which he informs you that he will be absent from Switzerland for several weeks, we have the honour to reply to these papers.

It is true that your Government has corrected in their order of the 30th of April, a good deal of what was written in their order of the 1st idem. Nevertheless, we believe that your Government is not yet perfectly appreciative of the superiority of our system, chiefly on account of some errors in Major Scott's and in your reports, which we have since corrected. Therefore we beg to be allowed now to furnish a confirmation of the statements which we have already sent you, to correct the mistakes that have been made, and to apply our system, as well as we can to the Coonoor Ghaut.

The subject of the Coonoor Ghaut railway, being by the last order of the Madras Government placed on a new footing, we are in doubts, as to whom we should offer these detailed statements; whether to the

* For drawing and description, *see* Engineering, Vol. XX., (1875,) page 189.

† Engineering, Vol. XX., (1875,) page 187.

Madras Railway Company, or to the India Office in London, or to your august Government. We beg, therefore, to be allowed to address this letter to you, and request you to forward it to whomsoever you may think the proper party.

I. Actual cost of executed Ladder–Rail Railways with a gauge of 4 feet 8½ inches.

(*a*). *Vitznau Rigi Railway*, near Lucerne, (Switzerland.)—Gradients, maximum 1 in 4, average 1 in 5, length 3·34 miles. Dr. Pole has correctly informed you that "the Capital of the Company was £50,000 which sufficed for the first establishment of the railway, but the large development of the traffic has rendered necessary the doubling of 1½ miles of the line, the provision of more stock, the erection of enlarged stations, workshops, &c." But we add that on this line are now running ten locomotives and seventeen carriages, that the workshops have been enlarged, and that the stations are as comfortable as possible. Therefore, the entire outlay has risen to £88,268, as you will find in the report of the Rigi Railway for 1874, page 16.

This gives a rate of £26,427 *per mile.** There is, however, this to be said, that this railway was constructed at a time, when the prices of everything, especially of iron, were very low, and when wages were half what they are now. The information supplied to you by a gentleman from Lucerne is not at all correct, for the work was commenced after mature consideration, and no experiments were made after it was completed.

(*b*). *Kahlenburg Railway* from Vienna, (Austria.)—Gradients, maximum 1 in 10, averge 1 in 17·9, length 3·1 miles, *with a double line throughout its whole length.* Compensation for land was unprecedently high, because the Austrian Government did not permit us to appropriate it at a fixed value. Similarly, the cost of the very ornamental stations which had to be erected at Vienna was very large. Thus the railway cost £2,00,000. Therefore a mile of the *double line* cost £64,516 †

* This is for a line of which one-half has a double track.

† This line was begun in May 1873 and opened in ten months. It received no advantages beyond the mere concession; and owing to the exorbitant demands of the landowners, it proved a commercial failure, the payments to them amounting to £[illegible] on a line of only 3·1 miles in length. The bearing rails each weigh 40 lbs. per yard. The centre rack between them is composed of two U-shaped pieces of rolled iron, into which the wrought-iron teeth forming the rack are placed when the former are hot, and they are secured in position by the contraction of the metal. The rack is formed in lengths of 9·8 feet, and weighs 36·9 lbs. per lineal foot. The rolling stock consists of 6 locomotives, 16 passenger carriages, and 4 goods waggons, 12,000 to 15,000 persons per day being able to be conveyed. *Proc. Inst. C E., Vol. XLI.*, (1875,) page [illegible].

(*c*). *Schwabenburg Railway* from Buda Pest, (Hungary.)—Gradients, maximum 1 in 9·7, average 1 in 11·8, length 1·8 miles.

The outlay on this line was £50,000 or £27,777 per mile.

The rolling stock of this railway is to be enlarged this year, because the traffic has so much increased.*

(*d*). *Arth Rigi Railway* near Zug, (Switzerland.)—Gradients, maximum 1 in 5, average 1 in 7·5, length 5·5 miles. (Besides this length of ladder-rail railway, there is a length of the ordinary line between Arth and Oberarth ·86 miles long, which we do not here further notice). Much of this line being composed of rock, the cost of benching for the railway was greatly enhanced. The whole cost of this line thus amounted to £1,60,000 or £29,100 per mile. This railway will shortly need more rolling stock, which now consists of six engines and twelve carriages.

(*e*). *Rorschach Heiden Railway*, from the shores of Lake Constance, (Switzerland.)—Gradients, maximum 1 in 11, average 1 in 14, length 3·4 miles.

Actual cost £88,000 or £26,000 per mile.

The above statements show that none of the ladder-rail railways which we have constructed have cost less than £25,000 per mile.†

II. Detailed Statement showing the cost of the Ladder-Rail Railway.

It is obvious that the cost of the surveys, of compensation for land, and of benching out to form a roadway for the rails, in short of everything except the permanent way, differ in all countries. Still we should be able to prepare an approximate estimate for the Coonoor Ghaut with the use of the rates in Appendix P, (in Public Works G. O., No. 1213 of 30th April, 1875,) if we had in our hands the survey of the site of the railway. If you desire our opinion on this point, please send us the plans with the altitude heights marked thereon. In the absence of that survey, we will confine our opinion to the cost of the permanent way and of the rolling stock.

* The concession for this line was for forty years, all land being granted free and taxation remitted for fifteen years. The track itself is a single one, but land and works have been taken for a double line. It was commenced in the summer of 1873, and opened for traffic in the following year. M. Cathray, a Swiss, was the Engineer. *Proc. Inst. C.E., Vol. XLI*, (1875,) *page* 276.

† In Switzerland, eight lines provided with the central rack have been either constructed or are in various stages. *Proc. Inst. C.E., Vol. XLI.*, (1875,) *page* 276.

Permanent Way.—(*a*). Cost of the permanent way of 1 mile of the ladder-rail railway with a gauge of 4 feet 8½ inches *at a port town in Europe.*

	Cost per mile.
	£
2,145 Sleepers of oak, 6 inches deep by 7 inches wide by 7 feet 10½ inches long, including screws and labour, at 5*s*. each, ..	536
3,520 Running yards of longitudinal timbers of deal wood 6 × 7 inches, including screws and labour, at 1*s*. 7¾*d*. per yard,	290
1,760 Running yards of rack-rail, with fish-plates, angle irons, rivets, bolts for the rack, screws and nails, &c., at £1 16*s*. 6¾*d*. per yard, ...	3,218
64 Tons of bearing rails, at 36 lbs. per lineal yard, at £14½ per ton, ...	928
2¼ Tons of spikes, at £54½ per ton, ...	123
1·2 „ of fish-plates, at £17 per ton, ...	20
·48 „ of bolts, at £54½ per ton, ...	26
1,760 Running yards of tracklaying, at 3*s*. 7½*d*. per yard, ..	319
1,760 „ „ of ballasting and tamping, at 1*s*. 10*d*. per yard,	161
Contingencies, ...	47
	5,668

It must be remarked that the price of iron is just now lower than it has been. We could therefore reduce by 8 or 10 per cent. the cost per mile, if the prices remain the same when you give us the order as they are now. The cost per mile at a port town in Europe would thus be only £5,200.

(*b*). *In India*—	£		Per mile. £
The cost per mile as above, ...			5,200
Add for wider gauge, *i. e.*, 5 feet 6 inches—	£		
For longer sleepers, ...	52		
„ heavier rails, ...	144		
Ballasting and tamping, ...	28		
		224	
Add for freight from a port town in France to India, at £7 per ton for 110 tons,..		770	
Per kilometer, ...		994	
Or per mile, ...			1,590

Cost of Permanent Way per mile in India, .. 6,790 (at present prices).

Rolling Stock.— A. *Engines.*

(*a*).—*A locomotive of the Vitznau Rigi-Railway*, with vertical boiler, which can push up on a gradient of 1 in 5 a paying load of 9 tons, at a speed of 3·1 miles per hour, costs at the workshops in Switzerland, £1,800.

(*b*). *A locomotive of the Arth Rigi-Railway* (also applied on the Kahlenburg on the Schwabenburg and on the line from Rorschach to Heiden), with horizontal boiler, which pushes up on inclines of 1 in 8 a paying load of 25 tons at a speed of 5 miles an hour, costs at the workshops in Switzerland £2,200.

(*c*). *A locomotive of the mixed system* with horizontal boiler, which is able to run as well on the ladder-rail as on the ordinary railway, and which pushes up on an incline of 1 in 10 of the ladder-rail line a paying load of 30 tons at a speed of 4½ to 5 miles per hour, and upon the ordinary railway on an incline of 1 in 28 the same load at a speed of 7½ to 9 miles per hour, costs at the workshops in Switzerland £2,400.

The gauge of the above three engines is 4 feet 8½ inches. The order of the Madras Government directs that "the engines used for the ghaut ascent must be capable of working also into Mettapolliam, to avoid the necessity of having anything more than a roadside shed at any such unhealthy localities as Kullar or Burliar." Engine (*c*) would exactly serve this purpose. This engine on the Indian gauge of 5 feet 6½ inches (and if desired constructed for a higher speed) would cost at the Switzerland workshops £2,640, or delivered at Marseilles £2,840. But if the order for these engines was received immediately, looking to the present lower prices of iron, we could deliver them at £2,400 and £2,600 each at those respective places.

B. *Carriages.*

As stated in our letter of the 30th of December last, the cost of our railway carriages delivered at Marseilles is as under:—

	£
One 1st class carriage for fifty-four passengers without windows, but with venetian blinds as on the Rigi, ...	440
One second-class carriage do., ...	380
One goods wagon capable of carrying 7 tons of paying load, ..	220

All the above carriages have cog-wheels, which can at pleasure, in a moment, be engaged in the rack rail by an axle brake. Carriages of the above kind, enlarged to suit the Indian gauge of 5 feet 6½ inches, would cost 20 per cent. more.

III. The cost of the Ladder-Rail Railway compared with that of the Fell Railway.

(*a*). *Surveys, preliminary expenses, and supervision* must cost per mile the same in both systems. Therefore, as Major Scott has estimated Rs. 15,000 for the Fell system, it is not correct to place a larger amount against the Ladder-rail railway.

(*b*). *Excavation and embankments.*—You will find that what we now state is the fact, viz., that the embankments and cuttings become less in quantity as the gradient increases in steepness, for the traced line can then be made to fit more closely to the natural slope of the ground.* The cost of excavation and of embankment are thus decidedly less in the Rigi system. But not being in possession of the plans of the Coonoor Ghaut, we cannot state what this reduction will be, so we will forego this point in our favour.

(*c*). *Permanent way.*—We have before explained in detail that the permanent way of the Rigi system costs per mile £6,790. On Mount Cenis, the cost of one mile of the Fell system on a gauge of 3 feet $7\frac{3}{10}$ inches was as follows :—

		Cost per mile. £
2,145	Sleepers of oak 7″ × 9¼″ and 6 feet 10½ inches long, at 7*s.* 4*d.* each, ...	787
1,760	Running yards longitudinal timbers 9¼″ × 9¼″, including screws and labour, &c., at 3*s.* 2½*d.* per yard, ...	282
198	Tons of rail (at 75 lbs. per yard), at £14½ per ton, ...	2,871
4	Tons of fish plates (1,126 in all), at £17 per ton, ...	68
·96	Tons bolts (2,253 in all), at £54½ per ton, ...	53
4,290	Chairs at 20 lbs. each = 43¼ tons, at £22½,...	979
534	Chairs at the joints of the middle rail at 22 lbs. each = 5 tons, at £32 per ton, ...	160
1,786	Chairs in the intermediate spaces of the middle rail each 16 lbs. = 14 tons, at £22½ per ton, ...	316
1,760	Running yards of track laying, at 3*s.* 7*d.* per yard, ...	319
1,760	Running yards of ballasting and tamping, at 1*s.* 10*d.* per running yard,...	161
	Contingencies, ...	55
	Cost per mile of Fell's Permanent Way, ...	6,051

* This is an important practical fact worth noticing.

		£
Brought forward, ...		6,051
Add for widening gauge from 3 feet $7\frac{3}{16}$ inches to 5 feet 6 inches for sleepers 2,145, at 2*s*. 5*d*. each, ...	260	
For rails (to have a weight per lineal yard of 85 lbs.)* 26 tons, at £14½ per ton, ...	378	
Ballasting and tamping, ...	91	
		729
Freight from a French port to India, 291 tons at the same price as before, viz., £7 per ton, ...		2,037
Cost of Fell's Permanent Way in India per mile,		8,817

(*d*). *Masonry Works and Girders.*—As we pointed out under (*b*), the embankments and cuttings will decrease in size as the grade increases in steepness. The bridges will do likewise. But here also for a second time we will forego this advantage in favour of our system, as we do not possess the plans of the Coonoor Ghaut. We will therefore take Major Scott's figures, viz., Rs. 20,000 per mile.

(*e*). *Stations and Buildings.*—Both lines will need the same number of stations, &c., independent of their length, as they connect the same places. Therefore as Major Scott estimates for the whole line £12,000 the rates per mile for the ladder-rail railway—

	RS.
7 miles long will be, ...	17,140
And for the Fell line 12 miles long will be, ...	10,000

(*f*). *Rolling Stock. A. Engines.*—We will assume a traffic that will need seven engines of the kind (*c*) of the ladder-rail railway. Such an engine pushes up 18 tons on a gradient of 1 in 8 at a speed of 6·2 miles per hour. The seven miles of the ladder-rail railway will thus be traversed in 67 minutes. Let us suppose that 23 minutes are needed for taking in water and for oiling the engine, &c., and that each engine works nine hours a day. Then each engine will push up and down 108 tons per day, or all the engines 756 tons. With the locomotives on Fell's principle on Mont Cenis, 18 tons were taken up by each engine at a speed of 8·3 miles per hour on a gradient of 1 in 13. As the Fell system will ascend the Coonoor Ghaut in 12 miles, each engine will require 87 minutes to push up a paying load of 18 tons. Taking as before 23 minutes for taking in water, &c., and nine hours for working per diem, the same total load of 756 tons will require eight or nine locomotives on the Fell principle.

* These rails are much heavier than those entered in the Rigi system estimate.

If, therefore, the traffic on the Coonoor Ghaut stands in need of seven engines on the Rigi principle, it will require eight or nine locomotives on the Fell principle to ascend the same height, and to do the same work in the same time. The engines for the Fell railway being much more complicated than those on the Rigi system, (because there are four instead of two cylinders, four instead of two driving wheels, and because they are constructed much heavier in every way,) they will cost on the Indian gauge, and including freight to a French port, £3,000 each.

B. Carriages.—The cost of each of these on the Fell line will be the same as those on the Rigi, but more will be needed in proportion to the greater number of engines. Thus if the ladder-rail railway stands in need of 21 carriages, the Fell railway which ascends the same height will require 25 or 26 carriages.

Thus the outlay for rolling stock will be on the ladder-rail railway—

		£
7 engines, at £2,600 each, ...		18,200
21 carriages, at an average price of £400 each, ...		8,400
180 Tons freight to India, at £21 per ton, ...		3,780
		30,380

On the Fell Railway—

From 8 to 9 engines, at £3,000 each, ...	25,500	
From 25 to 26 carriages, at £400 each,...	10,200	
220 Tons freight to India, at £21 per ton,	4,620	
		40,320

Or the rates per mile will be—

For the ladder-rail railway 7 miles long, ...	4,340
For the Fell railway 12 miles long, ...	3,360

(*g*). *Electric Telegraph and Fencing* must cost the same per mile in both systems. Therefore as Major Scott takes £150 per mile for the Fell line, the same must be allowed for the Rigi system.

(*h*). *Land Compensation.*—This is also the same per mile in both systems, and may be taken as Major Scott does at £50.

(*i*). *Contingencies.*—We cannot understand why Major Scott puts a larger outlay per mile against the ladder-rail than he does for the Fell system. We will, however, raise no further objection to it and retain his figures.

Comparison of the cost of Railways on the Fell and Rigi principle applied to the Coonoor Ghaut on the Indian Standard gauge.

	Particulars.	Fell Railway gradient 1 in 12.	Rigi Railway gradient 1 in 7.
		Cost per mile. £	Cost per mile £
(*a*).	Surveys, preliminary expenses, and supervision, ...	1,500	1,500
(*b*).	Excavation or embankment, (formation of roadway,) ..	2,000	2,000
(*c*).	Permanent way and ballasting, ...	8,780	6,790
(*d*).	Masonry works and girders, ...	2,000	2,000
(*e*).	Station buildings, gates and crossings, ...	1,000	1,714
(*f*).	Rolling stock, ...	3,360	4,340
(*g*).	Electric telegraph and fencing, ...	150	150
(*h*).	Compensation for land, ...	50	50
(*i*).	Contingencies, ...	771	895
	Total per mile, ...	19,611	19,439
	Mileage on the ghaut, ...	12	7
	Total cost of construction of ghaut line, ...		1,36,073
	Extension from Metapolliam to Kullar, ...		50,000
	Total cost of the line from Metapolliam to Coonoor,..	2,85,332	1,86,073
	Interest on outlay during construction at 6 per cent,	17,120	11,164
	Capital charge,	3,02,452	1,97,237
	Whereas Major Scott estimates this at	2,58,655	1,86,437

We have thus established—

(*a*). That the cost of one mile of the Fell line will be £172 more than that of the Rigi railway.

(*b*). That the cost of the whole line on the Fell principle is in round numbers £1,05,000 more than that on the Rigi principle.

IV. *The cost of Maintenance and Working.*—Few if any persons here are acquainted with the circumstances of the Indian lines, still less with those of the Coonoor Ghaut. We are therefore quite unable to form an estimate of the working cost in that place. But we can state from our experience in Europe, and from our detailed calculations thereon, that the working expenses on a ladder-rail railway on a gradient of 1 in 7, are in Europe about 30 per cent. cheaper than those on a Fell railway on a gradient of 1 in 13.*

* This is an important fact confirmed from other sources.

V. *Recapitulation.*—In this fresh discussion of the question, the following points have been established :—

*(a). The actual cost of the ladder-rail railways, which have up to date been constructed in Europe, has never been less than £25,000 per mile. Nevertheless £20,000 per mile will probably suffice to construct a ladder-rail railway on the Coonoor Ghaut.

(b). The Fell locomotive will not carry up twice the paying load which the Rigi locomotive pushes up. The load is the same in both principles, viz., 18 tons.

(c). It is true that the mechanical principle of the Rigi system does not allow of a high absolute speed. But the effect on the Coonoor Ghaut will be that the ladder-rail railway of 7 miles in length, will be ascended at a speed of 6·2 miles an hour in 67 minutes, whilst the same height can only be climbed up in a length of 12 miles by a locomotive on the Fell railway at a speed of 8·3 miles an hour in 83 minutes.

(d). The cost of a mile of the ladder-rail railway will be about £172 less than that of a mile of the Fell railway including rolling stock.

(e). The whole Coonoor line will be about £1,05,000 cheaper on the Rigi principle than on the Fell plan.

(f). The expenses for working and maintenance are about 30 per cent. cheaper on the ladder-rail railway than on the Fell railway. We may further notice that—

(g). The power of the Rigi engine is not limited (as is the Fell engine) to the variable adhesion of the wheels to the rails. By strengthening the engine, and the rack rail, the power of pushing up loads can be increased to almost any extent, and can be made to work quite independent of weather.

(h). The wear and tear of the rolling stock, rails, and racks is very insignificant in the Rigi system, while the rails of the Fell line must be renewed once in seven or eight years; during the five years that it has worked, the Rigi rails have been hardly at all affected.

(i). As we have before explained, the combined engines can run on the ordinary rail as well as on the ladder-rail. Thus the rack can be discontinued and resumed at intervals without stopping the engine.* Such a railway exists in Ostermundingen near Bern (Switzerland). We con-

* This improvement is making the Rigi system more generally applicable.

tructed and started it four years ago. The results of its working are excellent.*

(*k*). Finally, we beg to state that the security of the Rigi system satisfies every one, and is as perfect as can be conceived. This is confirmed by the fact that during five working years, no accident, however slight, has occurred on the lines we have made.

We should much like to come to terms with the Madras Government concerning the delivery and setting up of the permanent way, the delivery of the rolling stock, and the starting of the working of the line. If required to do so, we shall be happy to send one of our Engineers to advise on the direction which a line on our system should take on the Coonoor Ghaut.

We beg you will be good enough to lay this matter before the Madras Government and inform us of the result.

O. Z.

The Rack-rail Railway system in Germany.

Translated from the German by Captain J. L. L. Morant, R.E., *District Engineer, Nilgiris.*

(From the Basle News of November 1876.*)*

" The *Swabian Mercury* gives the following description of the recently completed rack-rail railway to the iron mines of Wasseralfingen in the Duchy of Wurtemberg, which was opened last October.

This line, interesting as being the first rack-rail line in Germany, is worked with light trucks made wholly of iron, which convey the ore from the mines to the foundries, and the slag back again. The trains are drawn by a locomotive specially constructed for this line. At some distance from the foundries there is an engine shed, where the locomotives are kept when not in use, where they are cleaned, and where, if necessary, they are repaired. The locomotive (to correspond with the small mineral wagons) is but of moderate size, though of elegant design, and was

* The Ostermundingen railway was constructed four years ago to open up certain quarries as well as for passenger traffic. After a level run of 4,920 feet, it rises with a gradient of 1 in 10, for a distance of 1,640 feet, where it again takes a level run into the quarries. The central rack rail is only laid on the rising portion of the line, the locomotive being constructed so as to work like an ordinary engine until it reaches the ascent, when the machinery is put in gear with the rack. This railway connects with one of the main lines of the country, *the goods wagons used on both lines being the same. Proc. Inst. C.E., Vol. XLI.*, (1875,) *page* 277.

constructed by Messrs. Heim and Riggenbach at Aarau. Guided by these two gentlemen, it left its shed and travelled over the smooth rails of the foundry, all the furnaces and workshops of which are connected by rails, forming a perfect net work. Adjoining the foundry, another company have established works for manufacturing very superior bricks out of the slag mixed with slaked lime. The locomotive, on the day of trial, was attached to 12 trucks, specially constructed for convenience in loading and unloading the mineral; these were filled with slag dust, and some were boarded for the occasion to form a platform, on which the numerous gentlemen, who came to witness the experiment, took their places. The train was started amidst the cheers of an assembled crowd of mechanics and miners, who had been promised a special trip in the afternoon. The train travelled at speed towards the incline of "Appenwangs" over the plain on smooth rails rising 1 in 40. As we approached the foot of the incline, the rack-rail railway looked proudly down upon us from a great height. Its gradient is 1 in 11. We passed from the smooth to the central rack-rail successfully, and went for some distance over the latter, when we returned to the foundry. The method of providing for the safe passage of the locomotive from the smooth to the central rack-rail is not so easy as might be supposed. A peculiar and beautiful arrangement is necessary. It is as well to mention this, and to draw attention to the way in which the machinery of the locomotive is gradually brought into connection with the central rack-rail. 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. This arrangement requires to be seen to be thoroughly understood and appreciated. In conclusion, we can with pleasure testify that the rack-rail railroad at Wasseralfingen admirably answers all its purposes."

(*From No.* 19 *of 'The Swiss Railway Journal.'*)

"The cog-wheel locomotive constructed in the Workshops of Aarau for the Wurtemburg Mining Company at Wasseralfingen has been illustrated in this Journal. On the 27th and 28th of October, it was, under the personal direction of Mons. Riggenbach, first tried there in the presence of the following officials:—The Consulting Engineer, Mons. Morlock, the Mining Director, Mons. Erhardt von Knapp, the Railway Inspectors, Messieurs Hahne and Heim, the Professors of Technics, Messieurs Müller and Dorn, and many other leading gentlemen of the Railway and Mining Departments. The results of the trial were in every particular highly satisfactory. The line, on which the locomotive was tried, is of metre-gauge. It connects the iron foundries at Wasseralfingen with the mines, which are 262½ feet higher than the foundry. The line is made partly in the ordinary way on an incline of 1 in 40, and partly with a centre rack-rail on the Rigi system with a gradient of 1 in 13. It being essential that but one locomotive should drag each train over both lines, the locomotive referred to has been constructed to traverse the smooth and more level rails, and has been also provided with a cogged driving-wheel to run over the rack-rail portion. It performs both duties satisfactorily, as the trials witnessed at Wasseralfingen plainly showed. Nine loaded trucks, weighing in all 28 tons, were drawn up the incline of 1 in 13 at a speed of nearly 9½ miles per hour; but, as a rule, the speed over similar rack-rail inclines is not intended to exceed 5 or 6¼ miles per hour. The above locomotive loaded with fuel, &c., and ready for starting, weighed 11 tons. Thus at the trial it dragged up an ascent of 1 in 13, a train weighing more than 2½ times its own weight, at a speed of 9½ miles per hour: whereas the locomotive on the Netliberg line on an incline of 1 in 14, in favourable weather, drags up only a train of its own weight. On the ordinary portion of the Wasseralfingen line, with the 1 in 40 gradient, the cog-wheel locomotive easily drew the above 28 tons of train weight at a speed of 12½ miles per hour. The chief difficulty of passing without slacking speed from the ordinary smooth line to the rack line and *vice versâ*, has by a clever arrangement been completely overcome."

J. L. L. M.

No. CCXXXII.

SECTIONS OF INDIAN WEIRS.

[*Vide* Plate XXX.]

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

THE accompanying *Plate* XXX.,—which shows at one view, and drawn to one scale, the sections of twelve different weirs built in the Punjab, N. W. Provinces, Bengal, and Madras,—was prepared for insertion in the new edition of the second volume of the Roorkee Treatise of Civil Engineering, as an useful and instructive illustration of this class of engineering works as existing at the present date in India. It is reproduced in the 'Professional Papers on Indian Engineering,' as it is believed that it will prove interesting to many readers of this publication, who may not have opportunities of consulting reports, &c., of different dates and from different parts of India, and of thus comparing various modes of weir building obtaining in this country. To render the information given in the Plate more complete, a few remarks in regard to each of the weirs represented will be here given.

1, 2. Myapur Dam, Northern Ganges Canal.—This is an example of an 'open dam,' differing from the unbroken 'anicuts' of Madras, and the solid weirs built in later years in Northern India. As stated by Sir P. Cautley, (in the following extract,) this dam is "in fact, a line of sluices with gates or shutters, which are capable of being laid entirely open down to the bed of the river during the period of flood." And this system he deliberately preferred (for the rapidly rising rivers of India) to that of a long unbroken weir with elevated sill, such as now generally adopted in this country, and such as is used in Piedmont and Lombardy. In discussing the canals of Piedmont, Sir P. Cautley writes as follows :—

The water is taken from the river and directed to the mouth of the canal as in Lombardy, by a masonry weir unbroken in its whole length, excepting at one point, through which the surplus water escapes with great violence; between this weir and the regulator are sluices detached from the weir, for the purpose of passing off surplus the weir are ever likely to be puddled by the action of the water, being convinced that water into the bed of the river, and by these means regulating the canal supply. In Lombardy precisely the same plan is adopted, and in the case of the Muzza Canal, the weir extends completely over the bed of the river; and the regulating sluices, which are situated between the head and the bridge of communication for the railroad, are of the same description, and on the same principle as those used in Piedmont.

This system of detached sluices in the position which I have above described, is much approved of by the Italian engineers, as—independently of giving a ready escape for surplus water—they provide a scour, and thereby the means of getting rid of the silt and deposits which invariably establish themselves in the mouth of the canal.

On the Lombardy canals, and under the advantages with which their water reaches the canal heads, the elevation of the sills of the weirs does not appear to be of serious consequence in raising the beds of the rivers on the up-stream side. In Piedmont, on the contrary, where the weirs are built over rivers directly running from the mountains, the effects of deposits above the weir, as might have been expected, are of a very serious nature. At the time that I visited Ivrea and the head of the Ivrea Canal, this evil appeared to me to have reached a maximum, and large parties of labourers were employed in the water in removing the sand and gravel, and clearing an open channel in the direction of the canal head. It has been found expedient in the canal works in the North West Provinces of India, to avoid as much as possible any elevation of sill to the masonry dams which cross the rivers at the heads of canals; these dams are, in fact, a line of sluices with gates or shutters, which are capable of being entirely laid open down to the bed of the river during the period of floods. In rapidly rising rivers, like those in India, the method which has been adopted by our engineers is, I believe, the most appropriate. In some cases, perhaps, it might be modified with advantage, where the head supply for the canal must necessarily be raised to a considerable height above the dam flooring, as in the case of the Myapur works at the head of the Ganges Canal; but in such cases, the advantages of modification would be found in increased facility of management during floods, due to the diminished area of sluice surface, rather than in any particular benefit in the maintenance of supply.

This dam differs also from the weirs now generally constructed, in regard to its position in relation to the head sluices of the canal, which are, at Myapur, placed in a 'Regulating Bridge,' situated, not on the flank revetments immediately adjoining the weir abutment, but 200 feet or more down the canal channel. This is a defective arrangement, as the 'pocket' thus formed between the regulator and actual commencement of the canal channel is filled by an almost still backwater when the waters in flood are pouring over the dam: and this 'pocket' becomes shingled up, with 7 or 8 feet in depth of boulders and sand, and the supply entering the canal is reduced until this accumulation is cleared away. The dam is thus described by Sir P. Cautley:—

The left flank of the dam abuts upon an island, in which nearly one-half of its full width was excavated. The island at the point of contact, although terminating at a short distance below the work, is composed of compact earth and shingle, and affords a sound and efficient resting place for the flank walls. The right flank falls within the precincts of the branch, as it existed at the period when the works were lined out, and is consequently backed by shingle and soil excavated from that portion of the mouth which lies north of the regulator.

The floorings of the dam and of the regulating bridge are laid on one level, and the front line of the latter is the zero upon which the whole of the canal excavations are referable. The zero point was fixed by me on my original survey; it was, in fact, the bed of the branch at that period, as nearly as the calculated bed levels of the canal, between the head of the first set of falls at Bahadurabad, and the foot of the Gunes Ghat, would admit of.

The dam itself, which is 517 feet between the flanks, is pierced in its centre by fifteen openings of 10 feet wide each; the sills or floorings of each opening being raised 2½ feet from the zero line. These floorings are so constructed, that if necessary, they may be removed, and a flush waterway be obtained as low as zero. The piers between the above openings are 8 feet in height, so that the elevated flooring leaves the depth of sluice-gate equal to 5½ feet. The piers, however, are fitted with grooves for the admission of sleeper or vane planks, to which I purpose restricting the apparatus for closing the sluices, until experience has been gained of the effects of deposits on the up-stream side of the works, and the advisability, or not, of maintaining the raised sill to the openings. There are great advantages in the sill being raised, with respect to facilitating the opening and shutting of the sluices; the arrangement also reduces the gates to a moderate height, and consequently to a more manageable dimension for working; it admits, moreover, of the sluices being opened and closed in a much shorter period of time. Opposed to these advantages, however, is the certain consequence, I imagine, of deposits arising from a bar of masonry raised 2½ feet above the true level. The adoption of this bar, it will be understood, is purely experimental; and should its existence be found hereafter to be detrimental to the works, it can be removed.

The centrical sluices above described are connected to the flanks by overfalls, rising in gradations of one foot on three series; the overfall nearest to the flank being raised 10 feet above the zero point. The flank walls themselves are 18¾ feet in height, exclusive of cornice and parapet, which rise 5 feet above them. The top of the overfalls on the right and left, as well as that of the piers, is flat; the former being an esplanade varying from 7 to 10 feet in width, which during dry weather is connected by a temporary communication formed by planks thrown across the sluice openings. This esplanade is at each extremity terminated by a flight of steps, which gives access to store-rooms; in which, when the dam is laid open, and the woodwork removed, the latter is lodged for security. The two buildings for this purpose are situated on the flanks; their floors are raised 20½ feet from the zero point, and their interior dimensions are 30 feet in length by 16 feet in breadth.

The flank revetments, which are built on the right and left of the down-stream side of the dam, and between which the escape water has to pass, have been designed with an inclination inwards equal to 13 feet on a length of 80 feet.

Its main object is to keep the current in the centre and away from the sides, and it is more economical in its construction.

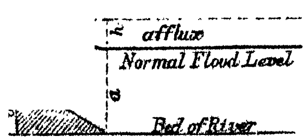
The transverse width of the dam platform is 44 feet, measuring from the up- to the down-stream face of the work. Of this measurement, 20 feet 11 inches are given to the tail which delivers the water upon the natural bed of the river, consisting of large boulders and shingle.

The raised sills, or floorings of the openings, above alluded to, are shown in *Plate* XXX., (*Figs.* 1 and 2) as at this time existing: being brickwork elevated sills laid on the original boulder-masonry floors on 'zero' level. The narrowness (44 feet) of the dam platform, contrasts strangely with the width of other weirs, (*e. g.*, Okhla, Bezwara, &c.,) but it must be remembered that the bed of the Ganges at Myapur consists of large and small boulders, forming a natural talus below the weir: and that owing to the backwater of the other open channels of the river, the bed of the Myapur channel below the weir has a tendency to rise instead of being scoured away. A new weir across the whole river, 2 or 3 miles above the Myapur dam, is now under construction; which will thoroughly modify the existing arrangements of headworks.

3. Narora Weir, Lower Ganges Canal.—This is the most recent of the large and important weirs lately built, and from the volume of the floods, the sandy nature of the river bed, and the absence of material on the site suitable for a weir of this description, the difficulties to be contended with have been very great. The dam proper is a solid wall of brick masonry 3,700 feet in length: the floor below it is of concrete, (3 feet,) covered over with brickwork, (1 foot,) and then with one foot of sandstone ashlar: and the talus below is formed of very large masses of block kankar brought from quarries at 30 miles distance. The up-stream side of the dam is backed with clay puddle, pitched on its outer slope with an apron of block kankar.

The length of the weir was settled by Major Jeffreys, R.E., as 4,000 feet, on the following data: an afflux (h) of $1\frac{1}{2}$ feet, when the river is at its highest, was accepted as perfectly safe: a maximum flood level 6 feet ($a - b$) above sill of weir: a maximum flood volume (Q), over the weir, of 2,00,000 cubic feet: a surface velocity (w) of approach of 6 feet: these figures applied in D'Aubuisson's formula,

$$Q = 3{\cdot}49\ lh\sqrt{h + {\cdot}035\,w^2} + 4{\cdot}97\ (a - b)\sqrt{h + {\cdot}02\,w^2},$$



give the value of l = length of weir 3,766 feet. Colonel Brownlow in reviewing the project and depreciating a proposed reduction of the length settled by Major Jeffreys, showed that a maximum flood of 2,30,000 cubic feet might not unreasonably be expected, and that taking into consideration the circumstances of the site, the light and friable nature of the soil of the khadir, and the lowness of the ridge which intervenes between the present channel of the river and the broad parallel trough of the Mahewah valley, it would be very dangerous to contract the weir and raise flood levels.

The necessity for well foundations, especially for a strong line of deep blocks along the lower end of the stone floor, and also for staunching all leakage by a puddle of clay above the drop-wall—with a view of holding up all the water possible, and thus losing none of the supply when the river is at its lowest—of stopping all flow under the floor to the risk of undermining and destroying it—and also of resisting retrogressive action below the weir,—was strongly urged in Colonel Brownlow's review of the project, as will be seen from the following extract. [The remarks on these points in regard to the Coleroon and Godavery anicuts (*vide* pages 250 and 256) should be compared with those in this extract.]

My reasons are, first, that all our experience in Upper India shows that where velocity of a stream is largely augmented by the construction of a barrier across it, permanent deepening of the channel below invariably takes place ; and secondly, that leakage will occur through the sandy bed underneath a dam with shallow foundations.

Deepening of the bed has taken place on all the torrents across which weirs have been thrown on the Eastern Jumna Canal, and it is now occurring at Okhla. It occurred below the Dhanauri dam on the Ganges Canal, until the obstruction caused by the dam was reduced, so that the normal velocity of the torrent was nearly restored, when the channel below partially silted up again.

This fact alone is a very strong argument against the proposed reduction of length of weir, but as our weir at Narora will in any case greatly accelerate the mean velocity of the floods, we must be prepared both for retrogression of levels, and the formation of very deep holes immediately below the talus of heavy material. Those at the tail of the Okhla weir after the floods of last season, were from 19 to 20 feet deep ; but whereas at Okhla the materials for filling them up, and thus resisting further retrogression, are readily available, we shall at Narora have nothing but a scanty supply of block kankar brought from long distances, or blocks of bèton manufactured at considerable expense.

In the latter case, a strong line of deep blocks, supported by the ruins of the talus, would stoutly resist any retrogressive action, whilst the materials for repair were being collected and prepared ; while the work on shallow foundations would run the greatest risk of being undermined and destroyed.

It is stated that the leakage, prevented by deep well foundations, is more imaginary than real, because long before the volume entering the canal is likely to be utilised, the bed of the river will have become silted up nearly to the crest of the dam and the upper layers of silt will have become more or less clayey, because leakage takes place through the banks as well through the bed, and finally because little or no leakage has been detected through the Okhla weir which has shallow foundations.

I cannot admit that the upper layers of silt deposited in the bed of the river above they are deposited by falling floods, and are swept out again by the full current of the next succeeding high flood. The scour which takes place immediately *above* any marked contraction of a stream is a matter of common experience, and is easily explained by the great relative increase in the bottom velocity resulting from the contraction.

The banks, on the contrary, will become permanent if the flanks of the weir are not turned, and they may ultimately become staunched by the clay brought down by the flood water. Besides the effect of the pressure of the water on the banks is not worth mentioning, when compared to that on the sand underlying the weir. I think, therefore, that any consideration of the leakage through the banks may safely be neglected. But even if it could not be, I do not see why we should not try and stop the leakage through the bed, because the banks are supposed likely to leak also.

The latter argument applies equally to the objection commonly urged against deep block foundations, viz., that a line of them cannot be made perfectly water-tight. It is surely better to block up $\frac{88}{100}$ths of the area through which leakage can occur, than to leave it all open because a perfectly water-tight partition cannot be made.

It may certainly be said that the Okhla weir does not leak very much just now, but it ought to be added that it has never been fairly tried, as the undersluices are kept constantly open. There are springs visible at the tail of the weir now with only five feet head of pressure, which may become very troublesome when that pressure is increased to 12 and 13 feet for several months together.

Apart from any consideration of the value in money of the water saved by a strong water-tight dam, the strongest necessity is, to my mind, laid upon us to economise every drop of the low water supply in the river, owing to its insufficiency for the requirements of years of drought.

Common justice to the cultivating community, dependent on the canal, seems to me to dictate the adoption of every reasonable precaution for rendering the whole of the short supply available for purposes of irrigation.

I have placed the deep line of blocks at the tail of the cut-stone apron, because I think that the latter, *if built at the proper level, and of a proper section*, will perfectly protect the blocks from any fear of action on the up-stream side, and that the real danger to be guarded against is the cutting back and permanent deepening of the bed of the river below the weir. I have allowed only shallow foundations for the drop wall, because I consider the line of blocks underneath it sufficiently protected by the cut-stone apron and deep foundations on the down-stream, and by the mass of heavy material on the up-stream side. The velocity of the current above the weir although amply sufficient to sweep away the loose sand of the bed, has been proved by the experience at Okhla, insufficient to move the heavy material of the apron.

To hold the talus together, it is traversed from end to end by solid concrete walls at intervals of 30 feet and 40 feet as shown in *Fig.* 3 of *Plate* XXX. This plan was found to be necessary at Okhla, where the third wall of 4 feet square section (*vide Fig.* 6) was adopted, as necessary, (to check movement in the blocks of the upper part of the talus,) although it formed no part of the original design.

The level of the cut-stone floor of the weir (as also of the floor of the weir sluices) is 3 feet below low water level: and as the floor is 5 feet thick, the laying of it entailed excavation to a depth of 8 feet below low water. To effect this, the upper row of blocks and lower row of wells were sunk to full depth: and hearted with concrete. (This was done by filling the hole below curb, and the lower one or two feet of the block or well by hydraulic cement let down in skips; when this had set, it formed a water-tight plug, and enabled the well or block to be pumped dry. The concrete core of the well or block was then put down in layers, and rammed in the ordinary manner). The interval between each pair of contiguous wells and blocks was closed by wooden piles, and the interval, included between piles and well, cleared of sand and filled with concrete. Clay puddle was also packed above the upper row of blocks. The space 33 feet in width intervening between the upper row of blocks and lower line of wells was then divided into compartments of about 40 feet in length by cross lines of shallow blocks, sunk, hearted and connected as above described. Thus large 'cofferdams' were formed, which were excavated to a depth of 8 feet below low water level, and the water pumped out by Gywnne's pumps: so as to allow of a 3 feet thick concrete floor being laid. On this a layer of brickwork 1 foot thick was added; and this in its turn was covered by an ashlar floor of cut sandstone blocks.

The weir sluices, 42 vents of 7 feet, are at the extreme right abutment end of the weir, so as to keep a clear channel open along the front of the immediately adjoining head sluices of the canal, whose floor is 3 feet above that of the weir sluices, and this allows the three lowest feet of silt laden water to pass by without entering the canal. The site of the weir stands 7 feet above low water level, which is the level of floor of head sluices, thus allowing 7 feet depth of water to pass down the canal. To obtain the extra 3 feet of depth, which may hereafter be necessary for *kharif* supply, some arrangement of tumbler, or movable shutters, along the crest sill of the weir will have to be provided.

It must be noticed that this weir is not yet (April 1877) completed, and the section shown in *Fig.* 3 is as proposed and under construction: the amount of material in the talus may hereafter assume a form more resembling that shown in *Fig.* 6.

(*Fig.* 6, of *Plate* XXXII. of this volume, shows the position of the weir and of the river for 4 miles above, with embankments and training works).

4, 5, 6. Okhla Weir, Agra Canal.—This is a remarkable work, in which the engineers of Northern India have exceeded the Madras engineers in the shallowness of foundations, in which the so-called 'Madras system' was supposed to differ widely from the practice of other parts of India. In this case foundations may be said to be entirely dispensed with. The lowest cold water level (649 feet above Kurrachee mean sea level) was adopted as the datum, and a trench was made for 2,438 feet across the dry sandy bed of the Jumna, 8 miles below Delhi, at this level: and in this trench was built in the winter of 1869-70, a wall 4 feet thick and 5 feet high of quartzite rubble masonry, laid in lime cement: a sloping apron of dry quartzite rubble extended 5 feet above this wall, and a sloping talus of similar material was laid for 100 feet below it: the floods of 1870 were allowed to pass over this weir, and left it unharmed. During the next winter, the wall was raised to its full height of 9 feet, and the talus was lengthened to 180 feet. The floods of 1871 overtopped the weir by 5½ feet, more than 1,00,000 cubic feet per second sweeping over it, while 40,000 cubic feet broke over the left shore embankment and inundated a large tract of country. The greatest velocity was 18·6 feet per second, and was found to be at 42 feet below the crest. Stone was worked out of the talus, and deep holes 20 feet deep were scoured out on the down-stream edge. During the next winter, 1871-72, the embankments were heightened and strengthened: a million cubic feet of stone were expended in filling up the holes below the talus. In 1872-73, a second wall —the true crest wall of the weir, parallel to, and 30 feet above the one first built,—was raised to a height of 9 feet: the interval between the two walls being filled with dry rubble. A third wall, 4 feet thick and 4 feet deep, was inserted in the talus, 40 feet below the lower wall: this has quite stopped all movement in the upper part of the talus: this wall is at the line of maximum velocity in floods. In March 1874 the canal was opened: but the upper one foot of the crest wall, forming the sandstone ashlar crest sill, is only now (in April 1877) being laid. The total quantity of stone in the weir is 46,60,000 cubic feet. The stone is the quartzite of the 'Ridge' of Delhi, and of similar out-cropping ridges in the country around. The right flank of the Okhla weir abuts on to a ridge of this rock, which has furnished an inexhaustible supply of material on the spot. The stone contains a large proportion of quartz, a little felspar, and protoxide of iron. It is very durable and excessively hard, rendering it unsuitable (owing to the labour and expense) for finely dressed ashlar work. The river bed has silted up to the crest level; but at the canal head a clear channel is kept open by the scouring action of the weir sluices placed at the right end of the weir: similarly situated to those of the Narora Weir as above described.

7. Dehree Anicut, Soane Canals.—This is a solid weir composed mainly of dry rubble, similar in form to the Okhla weir above described, but differing from that structure in having foundations to its three parallel masonry walls, which traverse the mass of dry rubble from end to end, and keep this mass together.

The discharge of the river has been ascertained to be, at the weir site, 10,26,172 cubic feet per second, the mean depth at highest flood being 11·64 feet, and the breadth between the banks 12,400 feet. The anicut is 8 feet high, and its length between abutments is 12,550 feet, or 2·35 miles. The depth of water over the weir in highest floods will be 6½ feet, with an afflux of 1¼ feet.

As two canals are taken off above this weir, one from each bank of the river, there are two sets of end weir sluices, one at each extremity of the weir. There is also a central set of weir sluices to provide a greater control over the regimen of the river. An ample supply of good stone, both for rubble and ashlar, is obtainable from quarries about 5 miles distant. The Soane differs from the Himalayan rivers generally in being confined within a permanent channel, so that no flank defences of any importance are necessary.

The three parallel walls of the dam are founded on shallow hollow blocks, sunk with the aid of Fouracres' excavators. These blocks have thin walls; for blocks of 6 feet interior width, a single brick thick was found sufficient, while for 14 feet blocks, the walls were built from 1½ or 2 bricks thick. When bamboo curbs were used iron stirrups were necessary, but such precautions were not required when rigid curbs of woods were employed. In the working season of 1872, five continuous miles of blocks were completed, at a cost of Rs. 12-8 per 100 cubic feet, of outside measurement.

8. Roopur Weir, Sirhind Canal.—This is a solid unbroken weir across the Sutlej, where it emerges from the low outlying range of hills below the Himalayas. The crest of the weir proper is 2,400 feet in length, with weir sluices at the left extremity contiguous to the Canal head. These weir sluices consist of 12-feet vents of 20-feet width each. The crest sill of the weir is 6 feet above cold weather water level; 8 feet above weir sluice floor; 8½ feet below the highest observed flood level. It is anticipated (for the weir is only now under construction) that the water will be headed up about 2½ feet above present highest flood level, when 2,00,000 cubic feet are passing over the weir. The upper and lower walls are built of rubble in mortar. The stone used for this weir is a sandstone, quarried at Nalagarh, distant about 15 miles from the weir, on the lowest outer spurs of the Himalayas proper.

9. Tajawala Weir, Jumna Canals.—The Tajawala Weir forms the headworks of the Eastern and Western Jamna Canals, which together irrigate over 5,00,000 acres of land per annum.

The site selected is about a mile below the foot of the Sewalik hills. The river bed is here deep, and defined, about half a mile wide. The bed is all boulders of various sizes, the slope about 20 feet in the mile, and the flood discharge 3,30,000 cubic feet, with maximum velocity of 19 feet a second, and depth in centre of 18 feet. The waves are probably 2½ feet above ordinary surface. The river moves the boulders with great violence and noise, and is a magnificent sight in flood.

The dam starts from the left bank, where the Eastern Jamna Canal head and sluices are situate, and slopes down and across the stream, a length of 1,735 feet, to the nose of an island—thus forcing the stream across to pass between this island and the right bank. This channel is 480 feet wide, and is entirely closed at right angles by the Western Jamna Canal sluices, which start from a point 1,000 feet below the end of the weir at the nose of the island. The Western Jamna Canal head is of course immediately above the sluices on the right bank.

The Eastern Jamna Canal supply is 1,600 feet in rabí and 2,000 in kharíf, provided for by a head of 16 openings, 6 feet wide, 6 feet deep.

The Western Jamna Canal supply of 3,200 and 5,000 cubic feet, has 35 similar openings.

The sluices are laid 4 feet below the head sills, *i. e.*, 10 feet below crest of weir in either case. For the Eastern Jamna Canal there are 7 openings of 20 feet. In the Western Jamna Canal, 10 of 20 feet. The rest of the 480 feet being built up solid to height of weir.

The body of the dam is as given in section—a floor 50 feet broad and 4 feet thick, slope 1 in 10—up-stream curtain laid 3 feet under, and 3 feet above bed, (now silted up level with crest)—down-stream curtain 10 feet deep—and a smaller central wall. The face of floor is of large boulders set on end. The crest is dressed ashlar. A tail of cribwork, 30 feet broad has been added for a length of 330 feet, where the river bed seemed unstable.

The whole work is boulder masonry. Boulders, and lime from limestone boulders, from the river bed near site. The clay for súrkí was found half a mile off. The mass of the work is built in random course. Piers, parapet, arch faces, &c., of dressed boulders.

The nose of the island is protected by a fine revetment wall faced with split boulder masonry, founded 14 feet below weir crest. The 1,000 feet of the edge of the island from this to the Western Jamna Canal sluices is sloped back, and faced with large boulders on end, with a toe or apron pitching 4 feet deep.

To prevent spill and close old canal heads, protective embankments run up 1,000 feet on the right, and 5,000 feet on left to foot of the hills. These are of earth faced with boulders.

Orders to commence work were received in December 1872, and it was practically finished by March 1877. The highest recorded flood over the crest of dam as yet has been 4 feet, and passed off doing no damage.

10. Streeviguntum Anicut over Tambrapoorney.—All the weirs above described have been, or are being, built in the Northern, or so-called Bengal, Presidency of India: those now to be described are Madras 'anicuts.' The Streeviguntum Anicut shown in section in *Fig.* 10 of *Plate* XXX., is of the same type as the Narora Weir, (though on a smaller scale,) having a drop wall with perpendicular fall, on to a cut stone floor, below which extends a dry stone talus.

The Tambrapoorney, which rises in the Western Ghats bordering Travancore and the Tinnevelly District, and flowing eastward, falls into the sea a few miles south of Tuticorin, drains a large tract of hilly and wooded country which is under the influence of both monsoons, and therefore, possesses not only an abundant, but a never failing, supply of water. This makes the Tambrapoorney for its size one of the most valuable sources of irrigation in the Madras Presidency, and its waters are consequently very extensively utilized by a series of seven Anicuts, which, thrown across the stream in ancient times, fertilize, from side channels, a considerable breadth of land on either bank.

The last of these anicuts is at Murdoor, about twelve miles above the site at Streeviguntum that was selected for the new work, (of which section is given in *Fig.* 10,) which has for its object the interception of the large quantity of water that finds its way by percolation, even in the driest weather, either through or under the various anicuts, or is returned to the stream as surplus from the channels on either bank, and which, together with the large volume of water brought down by the freshes, would escape to waste.

The *Anicut* is 1,380 feet in length between the wing-walls, raised 6 feet above the average level of the deep bed of the river, and the width at the crown 7½ feet; there is a front slope of ½ to 1, and in rear a perpendicular fall on to a cut-stone apron 24 feet wide, and 4½ feet in depth: beyond there is a rough stone talus of the same depth, and 36 feet in width, protected by a retaining wall. The foundation of the body of the work, and of the cut-stone floor in rear, is of brick-in-lime, laid on wells sunk 10½ feet in the sand, and raised 4½ feet above the wells, including the cut-stone covering; the retaining wall is built of stone-in-lime, and rests on a line of wells, sunk to the same depth, 10½ feet. The body of the anicut is of brick-in-lime, faced throughout with cut-stone, and furnished with a set of under-sluices at each extremity of the work to let off sand and surplus water. Each set of sluices consist of nine vents of 4 feet width each, lined with cut-stone; it was originally intended to have three more similar sets of sluices at equal distances throughout the length of the work, but, with the exception of the Kistna anicut, it was considered preferable to dispense with the intermediate sets of sluices.

11. Upper Anicut over the Coleroon.—The Coleroon anicuts to control the waters of this river and divert a portion into the Cauvery for the irrigation of Tanjore, were projected by General Sir A. (then Captain) Cotton, in 1834, and were completed in 1836. He was compelled to study economy, to use the cheapest materials, and to confine the dimensions of the works to the smallest scale compatible with stability. The section in *Fig.* 11 of *Plate* XXX. shows the upper anicut, not exactly as originally built, but according to the alterations suggested in 1839 by Colonel D. Sim of the Engineers, after the anicut had been breached. The following is an extract from his report, showing the risk incurred from the pressure of a head of water when the foundations of the drop wall are not so constructed as to stop all leakage, and the floors so short as to allow the water to be forced up through the talus beyond it.

The two Anicuts were begun and both completed in the early part of 1836. The upper one crosses the Coleroon about a hundred yards below its separation from the

Cauvery, and is 750 yards in length, being divided into three portions of unequal length, by two small islands or banks of sand in the bed of the river. The height varies from 5 feet 4 inches to 7 feet, and is 6 feet thick, with a foundation of 3 feet resting on wells 6 feet in depth. It is protected in rear by a substantial apron 21 feet broad, covered with cut-stone in chunam. The northern division has an under sluice of six vents near its middle, the centre portion one sluice of four vents, and two of two vents each, and the south part three sluices of two vents. These sluices are for the purpose of allowing the sand to pass through the anicut in high freshes, and prevent its accumulation above the work. This anicut was completed about the end of the month of April, and was breached in the following June during one of the freshes, about 80 yards of the northern division having been entirely destroyed. Some attribute the failure to the anicut having been undermined by the water being forced through its foundation by the heavy pressure during high freshes, and washing from under it the sand on which it rested.

The water it is evident was forced under the foundations, for it was observed bubbling up in many places through the apron below the anicuts, whenever there were 5 or 6 feet of water standing above them, and if it passed in considerable quantities, which there is reason to believe it did, it would be very liable to wash away the sand by degrees, and leave the work without support.

During the last two years, both anicuts have been materially strengthened by substantial aprons of cut-stone in chunam being constructed behind them, to break the overfall of the water, which have been executed in a very efficient manner; since these additions, the passage of the water underneath the foundations would seem to be considerably diminished, for it now spouts through the apron in only a few spaces and in small quantities, but I am not inclined to attribute this improvement so much to the aprons as to the large quantity of fine clay and mud which has collected in front of the anicuts, and prevents the water being forced underneath them.

The first and most important object is to secure the foundations against the risk of being undermined by the water being forced through them. This cannot be efficiently accomplished without considerable expense and labour. In Europe it would be done by a line of sheet piling being driven at 6 or 8 feet *in front* of the anicut, and parallel with it across the head of the river, the intervening space, after the sand is removed, being filled up with clay worked and pressed firmly into it, technically termed puddling. This forms a barrier impermeable by water, and effectually protects the foundations. In this country a row of wells may be substituted for the sheet piling, but the interior of the wells and the interstices between them, must be carefully puddled to a sufficient depth, in order to obtain the impermeable screen, for it is the puddled clay which obstructs the passage of the water. Above the wells I would recommend an addition in front of the anicut of the dimensions and form in the sketch, to strengthen the work and facilitate the passage of the river over it in high floods. The front of the anicut is made of a curved shape, as that form diminishes the pressure of the current upon it, accelerates the passage of the water over the anicut, and thereby decreases the rise of the river in inundations, and by the change produced in the direction of the current, prevents in some degree the great collection of mud which takes place before perpendicular walls.

12. Bezwara Anicut, Kistna River.—The idea of constructing a dam across the river Kistna to irrigate portions of the Masulipatam and

Guntoor Districts in the Madras Presidency, was entertained as far back as the year 1792 by Major Beatson: but it was not until 1847 that Captain Atwell Lake submitted a definite project for the work, and selected Bezwara as the site for the weir, where the river narrows to about 1,000 yards, and where there are two large hills one on either side close to the river's bank, furnishing an inexhaustible supply of material. The bed of the river is of sand. The opinion given by Sir A. (then Major) Cotton, regarding this site and question of a sandy bed, in 1848, will be interesting, in connection with the works constructed within the last few years on the sandy beds of the Ganges and Jumna at Narora and Okhla, respectively.

I consider the site an extraordinarily favourable one; and if, in addition to its other remarkable advantages, it had the only other which might appear desirable, viz., that of a rocky bed, instead of a sandy one, it would in my view make very little difference, none at all as respects the stability of the structure, and only perhaps Rs. 50,000 in the cost.

There is so deep an impression in people's minds respecting a sand foundation generally, that it is most difficult to investigate the subject properly. There is certainly one defect in sand as a foundation, viz., that if running water comes in contact with it, it will be swept away; but this is the only one; in other respects it is the finest foundation possible; it is indestructible and incompressible. Of the thousands of works which I have seen or executed on a foundation of pure sand, I never saw the slightest sign of a settlement in any one of them. We must therefore take care to remember that there is only one thing to be guarded against in building in sand, and that so long as it is protected from the action of running water, no work resting in it can possibly fail; and the remedy for this one defect is as plain and easily applied in situations such as this, as could be desired; it is simply to cover the sand, where it would otherwise be exposed to the action of the current, with loose stone. With this precaution, where it can be used, I consider sand a perfect foundation, and in the present case, loose stones can be used in any quantity, at a cost that is not to be compared with the importance of the work. The size or the quantity of the stone must certainly be proportioned to the strength of the current: if this is great, and only small stones can be obtained, the quantity must be so increased as that the slope of their surface may make up for their want of size. In rivers like these, having a velocity of four miles an hour, at the utmost, the largest stone to be found in their beds does not exceed two or three ounces; and these often remain for years in the same place. If the surface of the stones had a slope of, suppose, 20 to 1 they would require to be a pound or two in weight to resist the current; with a higher velocity and greater slope, larger stones would be required; but with such velocities as we have to deal with in these rivers, unless we make the anicuts very high, very moderate sized stones would be sufficient, even with a considerable slope; while at Bezwarah any sized stones can be used, and in any quantities, at, as I have said, an expense not to be considered in a work of this importance.

I think it is scarcely possible for any person upon a little consideration not to be satisfied that, with such a breadth of stone work extended below the anicut, it would be impossible for the water to get at the sand on which the body of the work rested, so as to wash it away. And it is equally evident that, in such a project, a lakh of rupees more or less in the cost cannot in the least affect the question.

Any how, I should suppose that it must be allowed that it is simply a question of the quantity of loose stone, and nothing more ; that is, that with a certain quantity of that material, the stability of the work is as certain as it could be on any imaginable kind of site, and further that, that quantity can be obtained at a comparatively insignificant cost.

My own opinion is, that the quantity allowed by Captain Lake will be found ample : I should not be at the trouble and expense of filling up any hollows in the bed with stone, but would first bring it all to a uniform level with sand, and then throw the loose stone in an equal thickness all over the bed. For the sand is continually changing about, and where the hollow now is, in a year or two there will be a high bank of sand, and on that the anicut would be built. I should, therefore, level the bed with sand to near the summer level of the water, and then throw the mass of stone across, making it of course of a uniform height the first year, however low it might be.

The section of the weir is not exactly similar in all portions, but that shown in *Fig.* 12 is a fair average type. The following is an extract from the specification as prepared in 1849 : from which, however, some deviations, as noted below, were made during the execution of the work.

The river at the proposed site is 3,860 feet across, on the crest of the anicut.

Of this distance, the anicut will occupy 2,950 feet, the bridge abutments and piers 510 feet, and the sluices, including wing-walls, 360 feet.

The foundation of the anicut will vary with the character of the river section. Where the bed is deep, it will be filled up to the level of the summer water with rough stone, and where it is high, wells will be sunk in the front and rear of the work, as far as practicable, below the same level.

Upon these foundations the body of the anicut will be raised alike throughout, namely, with a front wall nearly perpendicular, and a rear curved slope, both of rubble masonry ; the space between being filled with rough stone, and the crest covered in with rubble masonry, to be eventually, with the rear slope, capped with cut stone.

The height of the anicut above the summer level will be 16 feet, the breadth of the crest 12 feet, and that of the slope (horizontally) 48 feet.

There will be an apron in rear of the anicut of 90 feet in breadth, and 6 to 8 feet average depth.

The anicut sluices it is proposed to place, one at about 36 feet from each bank, with which and the head sluices they will be connected by wing-walls. The sluices are to have each 15 vents, of 6 feet in breadth, and from 10 to 15 feet in height. The floor is placed in the drawings at 9 feet below the crest of the anicut, but in the construction it must be fixed according to circumstances. The sluices will have front and rear aprons of cut stone, and a rear apron of rough stone of 150 feet in width, and 10 feet average depth.

As the work progressed, the officer in charge, Captain Orr, found that when the body of the anicut rested on a body of loose stone thrown in to fill up hollows in the river bed, as at the sites of the various breaches that occurred during the progress of the work, it was not only difficult, but almost impossible, to render the dam water-tight; the leakage at those places being, not mere percolation, as along the rest of the work which was supported on wells sunk in the sand, but strong continuous streams flowing, at a great depth, through the large open interstices of the rough stones, as through inverted syphons.

He therefore decided upon filling up the hollows with sand, and bringing the whole bed of the river under the work to one uniform level with sand, before commencing on the stone work: as had been proposed originally by Major Cotton, in his 'Note,' of which an extract is given above. Another alteration effected in the design, was the omission of the proposed cut stone covering to the weir. In August 1855, Captain Orr was able to report the completion of the weir, the following is an extract from his report:—

I have the honour to report that the anicut has been completed to the extent, and in the manner proposed by me in my letter of the 11th August, 1854, that is, the front retaining wall has been raised to a height of 20 feet above the deep bed of the river, and has been backed by a large mass of rough stone consisting of more than half a million of tons in blocks of all sizes up to five and even to six tons in weight, forming altogether a dam nearly 200 feet in width. At 100 feet from the front, a second retaining wall is built, having its top 6 feet below the crest; and between the two the surface of the work is roughly packed with stone on end, as tightly fixed together as possible, by quarry rubbish rammed into the interstices. Behind the rear wall the dam is continued for nearly another hundred feet, by masses of the largest sized stone. Thus the form and construction of the anicut greatly differ from the more finished but infinitely weaker section originally proposed for it, as the covering of the top and a portion of the slope with masonry of rubble and dressed stone is dispensed with, and in lieu of it a vastly increased amount of material, in the shape of large blocks of rough stone, has been employed. As two freshes of upwards of 30 feet each have now passed over the work, its stability has been well tested, and apparently with the most satisfactory results; for though the state of the rear portion of the dam cannot be judged of for some time till the river subsides, the crown and slope can be seen to be in good order, and with the exception of a stone displaced here and there, the roughly packed surface seems to stand extremely well. This proves that the masonry covering is not necessary; and therefore, as it can add nothing to the efficiency of the work, but would weaken rather than strengthen it, as shown in my letter above referred to, I would recommend its omission, and that all future outlay on the anicut be directed to the deposition behind it of additional quantities of stone in heavy masses, and to the puddling in front with clay. Some repairs and additions of rough stone will annually be required for some time to come; but the work being of a description to consolidate, and become more and more secure in course of time, the expense of its maintenance must ultimately amount to but a fractional percentage on its cost.

13. **Godavery Anicut.**—This grand work was projected by Sir A. Cotton, and built (for the most part by that officer) in 1847-52. The situation and object of the work was described in 1846 as follows :—

The Godavery river has its sources in the Ghats to the North West of Bombay near Trumback, and Nassuk, there being fed by the rains of the never failing South West Monsoon, it flows down into the Deccan ; in passing across which it receives the Manjurah and other tributary streams, and finally, after a course of upwards of 700 miles, enters the sea by several mouths between Masulipatam and Vizagapatam on the Coromandel Coast. Though the waters of the river itself never fail, the countries through which it passes are periodically more or less visited with drought, this is more especially the case on the Coromandel Coast, where owing to a periodical failure of rains, seasons of famine come round in regular cycles, when we are presented with the anomaly of a large population occupying a Delta of about 3,000 square miles of the richest soil in India suffering from the horrors of the famine : whilst the fertilizing streams of the noble river, which a bountiful Providence has furnished for the purpose of preventing such a calamity, are allowed to run to waste into the ocean ; instead of being husbanded by human industry, and turned to the purpose for which they were given.

It is to remedy these evils, and to apply the river to its legitimate purpose, that Major Cotton has, with great industry and talent, drawn up his plan of throwing an anicut across the river, and thus saving part of the waters for the regular irrigation of the Delta.

The design first prepared, provided for a perpendicular drop wall, with a cut-stone flooring below it, as employed on the Coleroon, (*vide Fig.* 11.) But this design was subsequently modified on grounds stated as below by General Sir A. (then Major) Cotton.

I find that the great quantity of cut-stone there proposed, will require so many more masons than the district can supply, so as to complete the work within a moderate time, that it would be very desirable, if possible, to give the work a form that would require less of this material. The facility of construction, involving the question of time is, next to security, the most important point. The delay of a year would no doubt cause a loss of one or two lakhs of rupees, and much more some years hence. I find from my late trials in the quarry, that it would probably take about 1,000 stone-hewers and stone-cutters to prepare the requisite quantity of cut-stone in two years, and from what I have yet been able to learn, I am afraid that nothing like this number could be procured ; the section I now forward, therefore, is such as, by avoiding an over-fall, excepting where the under-sluices occur, will admit of the principal part of the surface of the work being made of rubble work pointed with concrete, and finished with a surface of smoothed chunam, such as the sluices and other works are finished with in Tanjore, when not lined or covered with cut-stone. The principal part of the work will thus consist of loose stone, of which there is an unbounded supply, the greater part ready broken, and which can be brought to the work very rapidly by railroads.

This is the mode of construction originally used at the ancient native work called the Grand Anicut, which has stood for so many centuries. Part of it has indeed been raised and covered with cut-stone, but a few years ago part of it was still without that protection. On cutting through the work to make the under-sluices, the mass was found to consist of nothing but loose stone in mud, with the upper course only laid in chunam, and plastered with concrete. It has never required anything more than occasional renewals of the concrete, and has never been in any danger, or given cause of alarms.

Here, where material is abundant on the spot, and skilled labour scanty, it is worth considering whether such a rude mode of construction may not be adopted with advantage. In my first report on the Godavery, I proposed this kind of work; but I afterwards thought the employment of so vast a mass of materials would involve more delay than a more scientific construction. Since I sent in that report, I have had much more opportunity of investigating the subject, and my main objection to the use of rude materials has been removed. I find that round timber, straight, hard and durable, and perfectly suited for rails without sawing, can be obtained in great quantities at a most trifling cost. Such timber, from six to seven inches diameter, and 20 feet long, is procurable at from Rs. 20 to 25 per 100 logs; so that sufficient for a mile of single railway, including cross pieces, that is 20,000 feet lineal, will cost from Rs. 200 to 250. Such rails adzed to a level on the surface, with flat two-inch iron screwed down upon it, makes an excellent temporary railroad at so moderate a cost, that any length of it may be laid without an excessive expenditure; and by thus having several lines of railway, a great mass of materials may be conveyed in a short time, without confusion.

The section shows, however, another material alteration that I propose; and this is, to give the whole work a breadth of 18 feet in the clear at the top, so as to provide both an ample roadway during the time that the river is low, that is, during eight months in the year, and also to allow of a bridge being carried along it without altering the original work. It seems to me, that if this can be accomplished without exceeding the estimate, a very important point will be gained. To make the anicut fully answer the purpose of a bridge, while the river is low, I propose also to make the broad surface of the anicut two feet lower than the crown of the work; building a wall, two feet high on the upper side, to keep the roadway dry and prevent accidents. It is to be observed, that as the under-sluices will be of great capacity, they will discharge a large body of water, so that none will go over the work, excepting while the freshes are high; and as during that time there is but little traffic in the country, the anicut will thus almost answer the whole purpose of a bridge.

The total length of the weir is 20,570 feet; but it is broken into four sections separated by islands. The sections of all parts of the weir are not identical, but nearly so: and that shown in *Fig.* 13, is that of the longest, the 'Dowlaiswaram' section, 4,872 feet in length. After an inspection of the weir in April 1852, a report on the work was submitted, the following extracts of which will be found instructive:—

The Dowlaiswaram branch of the anicut with its wing-walls.—The section given to it has answered very well; and, excepting at the end near the wing-wall, there has been no injury to the work. The rough stone apron has sunk, but not very much, and has been raised and extended. During the last monsoon I cannot perceive that it has undergone the least change; but still I propose throwing in a small quantity of additional rough-stone, for greater security. This branch has however one defect: from the vast quantity of stone required for covering it, and the gradual deterioration of the quarry preventing its due selection, a great deal of the cut-stone is evidently too soft, and wears under the friction of the sand and gravel passing over it. Last year a great number of the soft stones were replaced with harder ones; and it has not worn so much this year; so that it is not necessary to replace any. The soft stones should, however, be gradually all removed. This does not in the least affect the stability of the work. The wing-walls are in good order.

Rallee branch with its wing-walls.—It is to be observed that the masonry of all the rest of the anicut is laid on sand between the front and rear retaining walls; but in other parts it cannot be washed away. Here the water passed through the stones under the front wall, and carried the sand under the masonry away. The consequence of this was, that the masonry in these places cracked, and in one spot sank till it rested on the rough stone. When the work was examined, it was found to be hollow underneath for a considerable distance. This is very instructive. There is no better foundation for masonry than sand, if it is secured from currents of water; it is indestructible and incompressible, and so far is just as good as rock; but in situations where currents of water can get at it, as it is not like rock, immovable, it is the worst of all foundations. All the part of the work thus undermined was broken up, and the masonry laid solid on the rough-stone: still this did not prevent the water passing under the work as before. A heavy bank of clay was thrown in front of the anicut last year, so as to cover the whole of the loose stone, and this stopped the leaks at the time; but they appeared again this year, and the water spouted through the rough stone apron strongly. We have now covered the front of the rough stone with a heavy bank of the tough clay mixed with chippings of stone from the spoil heaps in the quarry; and the leaks seem effectually stopped. I am of opinion, however, that it would have been better to have mixed the quarry clay with the lunka earth, as it would have made it more perfectly water-tight. The work does not appear at all endangered by these leaks. This work has been completed with a cut-stone covering, which is not much worn, partly because there was time to select the stone more, and partly I believe, because as yet less sand and gravel have passed over it than over the Dowlaiswaram branch.

14. Cheyaur Anicut, North Arcot.—A considerable number of tanks (between 40 and 50) situated in the Talooks of Trivatoor and Wundiwash in North Arcot on the south bank of the Cheyaur river, and entirely dependent on rains, exhibited a great falling off in their revenue. Government therefore sanctioned a proposal for erecting an anicut across the Cheyaur, and cutting channels, extending nearly 20 miles, for the supply of these tanks: the sanction was granted 15th September, 1851.

The channels were completed by the 24th October, 1852, the anicut was commenced on the 19th January, 1852, and, together with about 20 calingulahs, bridges, &c., was completed in August 1852.

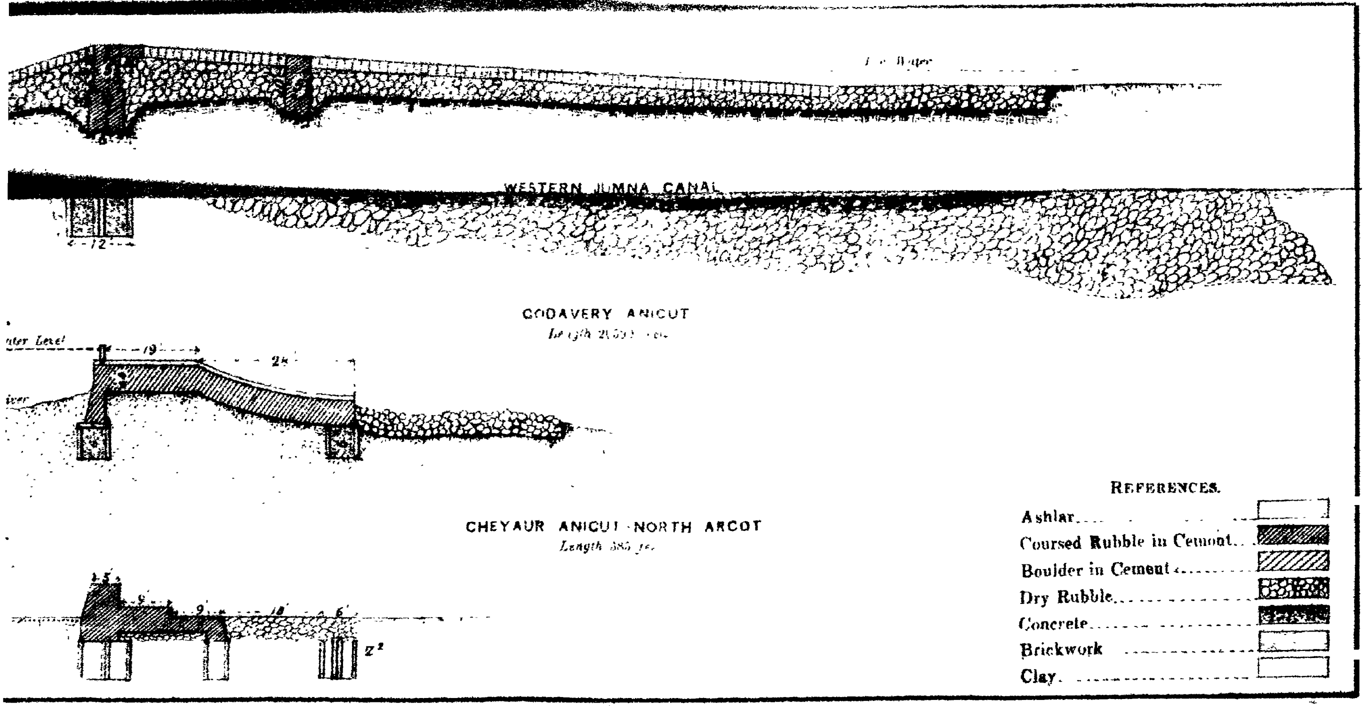
The anicut is 385 feet long, built upon two rows of wells of 4 feet 6 inches exterior diameter; the foundation on the wells 4 feet deep; the body of the anicut 5 feet high, 7 feet broad at bottom and 5 at top. It has an apron in two steps of 9 feet each in breadth; the fall on to the upper apron being 3 feet 6 inches, and from the upper to the lower 1 foot 6 inches. These aprons are 5 feet 6 inches, and 3 feet 5 inches thick, of rubble masonry very carefully laid, and each course brought to a level before commencing the upper one. The whole is covered with four inches of concrete of stone and lime. The end of the lower apron rests on wells. The rear talus is 18 feet broad, not in mortar as the above, but simply 3 feet thick, of large stones carefully laid on the sand of the river.

There are two sets of sluices, six vents each of 5 feet in each set; the piers between the vents are each 5 feet broad, and are, together with the piers for the bridge, built, above the level of the anicut, of brick-in-lime masonry.

A. M. L.

SECTIONS OF WEIRS.

Scale. 30 *feet* = 1 *inch.*



No. CCXXXIII.

EXPERIMENTS ON COMPRESSIBILITY OF SOIL AT MORADABAD.

Extracts from Reports by LIEUT. GREENSTREET, R.E., *and Notes by* LIEUT.-COL. Æ. PERKINS, R.E., *and* MAJOR-GENERAL ALEX. TAYLOR, R.E.

THE original orders in regard to these experiments addressed to the Executive Engineer, Moradabad, and were as follows:—

"I have the honour to request that you will build near No. 7 or No. 2 barrack, two walls 6 feet long, 1 foot thick, built 2½ feet into the ground and 7 feet apart.

"Load these walls with iron girders touching one another, bricks, and whatever may be necessary to give a pressure of eight tons on the foot.

"The level of some mark on the wall should be taken before loading, and carefully read after loading, to show the amount of compression that takes place.

"Please let the trench be of the exact width of the wall, so that no bulging upwards of the soil outside the bricks may be possible. The large 12-inch bricks will be convenient for use. The wall is to be straight from top to bottom without offsets, and may be brought up 2 feet above ground.

* * * * * * *

"Pun in the bottom of the trench before building. If there be any spare cutting whatever, pun in soil with the utmost care.

"Let the B. M. used for reference be a permanent point, say the plinth of a barrack, to which reference may be made at any time hereafter.

"Let the line on the wall be fine, admitting of the nicest readings. Do not let any other method of observation be substituted for what is here indicated."

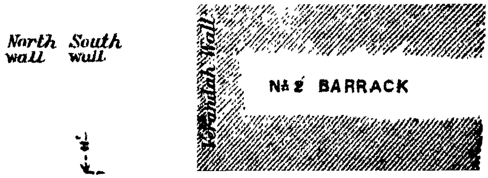
Extracts from a Report by LIEUT. GREENSTREET, R.E., *dated 27th September*, 1873.

Some questions having arisen as to the firmness of the upper stratum of clay which forms the foundation soil for buildings at Moradabad, and its strength to resist the weight of a heavy building without subsidence, several experiments were made by order of the Chief and Superintending Engineers, with a view to throwing light upon the subject. These experiments consisted at first of making holes of from 2 to 3 feet deep and ramming with heavy rammers; the level of the bottom of the hole being carefully levelled, both before and after ramming, so as to ascertain the amount of subsidence, if any. The results of these experiments have been reported from time to time as they were made, and therefore they need not be more particularly noticed here. It appears only necessary to point out that the above method was liable to errors, and was, for several reasons, likely to give unreliable results.

In the first place the soil was subjected to, and tested by its resistance, to a blow or a series of blows, the test being for resistance to impact instead of steady pressure. Besides which there was always the danger of the earth rammed out of one part of a hole being merely squeezed up into another. Moreover, the condition of the earth when dug and exposed to the air and sun for even a short space of time would be very different to that of the earth below the foundation of a wall which, when once filled in, is exposed to neither air nor sun.

Drawing showing how it was proposed to load the girders on the walls was forwarded by Executive Engineer, and was approved by the Superintending Engineer. This drawing had to be slightly modified in executing the work, as will be noticed hereafter.

The site fixed upon for the experiment was to the north of No. 2 barrack, in the position indicated on the sketch below.



Concrete Slab

The work of preparing the walls was begun on the 16th June and completed on the 23rd.

The excavation was first very carefully made, being of the exact size and shape of the walls directed to be built in the above-quoted instructions.

The bottoms of the trenches were first levelled on the required depth of 2 feet 6 inches below the ground level having been reached, so as to ensure their being both on the same level and perfectly horizontal.

They were then rammed for a couple of days with heavy rammers, and were again levelled with a Y level, any differences in the equal horizontality of the two being corrected.

The foundation trenches having been thus accurately prepared, the brickwork was built. The walls were constructed of 12-inch bricks accurately gauged, and cut where necessary, so as to be of the exact length. The mortar used was stone lime 1, súrkí 2.

The walls being built in English bond, and the joints of masonry three-sixteenth inch thick.

The walls were built 2½ feet below the ground level and 2 feet above it, being thus 4 feet 6 inches high altogether.

Each wall was surmounted by two Agra flag stones about 1½ inches thick, to act as wall-plates for the better distribution of the weights.

It was so arranged that the united weight of the two wall-plates on each wall was the same, viz., 154 lbs. They were laid in mortar, and carefully levelled.

A narrow line was made round each of the two walls at an exact level, about 16¼ inches from the tops of the walls, the line being scored into the corner bricks of the walls to prevent its being obliterated by rain.

This line was carefully levelled and referred to the point G on the plinth of No. 2 barrack, the reduced level of which is 655·18 above G. T. datum.

On 12th July, 1873, the wall-plates being on, and the test walls having had time to settle and the mortar to set, the first layer of girders was put across the walls. This layer consisted of 12 girders, 13 feet 9 inches long, weighing together 3 tons, 13 cwt., and 2 quarters.

In July there was heavy rain, much of the ground adjacent was under water, and it was very difficult to keep the water from the walls. Earth, however, was banked up against them and sloped outwards, so as to keep them drained as much as possible.

This weight was at this time as follows:—

Two walls, ...	=	2·868 tons.
Four Agra stone wall-plates 2 × 154 lbs. = 308 lbs.,	=	0·137 „
Layer No. 1 of 13 feet 9 inch girders 12 in number = 3 tons, 13 cwt., 2 quarters, ...	=	3·675 „
Layer No. 2 of 9 girders 26 feet long = 9 × 1·237 tons	=	11·133 „
Nine thin planks for packing between 1st and 2nd layers ¾-inch thick weighing 60 lbs., ...	=	0·027 „
Giving a total of ..		17·840 „

or 1·486 tons per square foot of foundations.

On 5th August, 1873, it was noticed that the walls were slightly subsiding, as indicated by the sliding rules. They showed a subsidence of $\frac{1}{16}$-inch at the west end, and $\frac{2}{16}$ at the east end of the north wall; there was scarcely any (if any) subsidence indicated on the south wall.

It will be observed that this subsidence took place in consequence of the constant pressure of the superincumbent weight in rainy weather, as no further weight had been added after the sliding rules had been fixed.

It is instructive also to notice that the conditions for drainage were slightly better for the south wall than for the north wall, in consequence of the greater proximity of the former to No. 2 barrack, from which the ground slightly falls away. At the beginning of August, orders came to recommence the work, preparations were therefore made to go on with the loading.

It will be seen from the tables, that the subsidence on the two walls was very unequal. The reason of this is not very apparent.

It is true, as has been already pointed out, that the north wall was perhaps slightly more exposed to the influence of the rain than the south wall, but yet the conditions of the two walls are so nearly alike, that the slight difference noted appears insufficient to account for the considerable difference of subsidence. But however this may be, the fact remains. Neither was there any possibility of the weight coming more on one wall than the other, as the greatest care was employed to keep the arrangement truly symmetrical.

Owing to this unequal subsidence, the whole structure leaned considerably over to the north, and consequently the work was delayed and much labour entailed: the space between the girders and the upright on that side is very small. It was sufficiently large, however, for the upward passage of the girders when first the scaffolding was erected, but owing to the girders leaning over on that side, the space was so much narrowed, that the girders had afterwards to be raised by other means.

About this time it was observed that the walls were out of the perpendicular.

The total weight of 8 tons per square foot remained on the wall from 1-30 P.M., on the 13th instant, till 12 noon on the 16th, or 70 hours. During a great part of this time, viz., from 4 P.M., 14th September, 1873, till 10 A.M., 16th September, 1873, there was very heavy and almost incessant rain, (from 10 to 12 inches of rain fell in this time,) it was impossible to keep the water from the walls, and the lower or north one sank considerably.

At noon on the 16th September the work of unloading commenced.

When the whole weight has been removed, a further report will be submitted as to the state of the walls, the amount of their obliquity, and such other points as may be brought to notice.

A table is annexed showing the weight and the subsidence due to the various increments of the weights. It shows in a condensed form much of what has gone before in the body of the report.

MORADABAD EARTH-TESTING EXPERIMENT.

Table showing subsidence of test-walls due to the various superincumbent weights.

Dates	Layer	Total weight	Amount of total subsidence in decimals of a foot				Weight per square foot of foundation area	Extra weight	Amount of subsidence due to extra weight in decimals of a foot				Total extra subsidence ÷ by 4, or average subsidence due to extra weight	Remarks.
			North wall		South wall				North wall		South wall			
			East end	West end	East end	West end			East end	West end	East end	West end		
		Tons.					Tons.	Tons.	Increments in settlement due to successive loads.					
12th July, ...	Walls.	2·868	...	...	...	...	...	...	...	...	...	...	...	
„ „ ...	Wall-plates and planks.	0·164	...	...	...	...	...	...	...	...	...	...	...	
„ „ ...	1	6·707	...	...	...	...	...	...	...	...	...	...	...	
„ „ ...	2	17·840	...	...	...	...	...	...	...	...	...	...	...	
„ „ ...	3	32·684	0·025	0·030	...	...	2·723	14·844	0·025	0·030	...	...	0·0275	
28th August, ...	4	46·291	0·075	0·085	0·055	0·075	3·857	13·607	0·050	0·055	0·055	0·075	0·0587	
30th „ ...	6	62·216	0·205	0·215	0·065	0·095	5·184	15·925	0·130	0·130	0·010	0·020	0·0725	Levels were not taken after the 5th layer was put on. Ditto 8th layer.
4th September,	7	70·091	0·350	0·380	0·065	0·105	5·840	7·875	0·145	0·165	...	...	0·0800	
„ „ ...	8	75·641	...	...	...	...	6·303	5·550	...	...	...	...	...	
5th „ ...	9	81·191	0·415	0·475	0·100	0·160	6·765	5·550	0·065	0·095	0·035	0·055	0·0625	
12th „ ...	10	91·766	0·525	0·635	...	0·225	7·647	10·577	0·110	0·160	...	0·065	0·1116	
13th „ ...	11	93·178	0·545	0·675	0·125	0·245	7·764	1·425	0·020	0·040	0·025	0·020	0·0262	
	Bricks	96·000	0·630	0·775	0·175	0·265	8·000	2·822	0·085	0·100	0·050	0·020	0·0637	There was no extra subsidence immediately after putting on the bricks; it did not occur till after heavy rain.
Total, ...	...	...	...	...	...	...	...	...	0·630	0·775	0·175	0·265	...	

W. L. G.

Note by Lieut.-Col. Æ. Perkins, R.E., *dated 30th September*, 1873.

A load of 8 tons per superficial foot was brought to bear on the foundation trenches of each of the two walls which measured in plan 6′ × 1′. Before giving the order for the experiment, I considered the disadvantage of having walls of such small base area from which to deduce results. But calculations showed that for a greater area the load would be so bulky, that it might be better to accept the experiment as it stands for what it is worth.

The ultimate compression of the soil was as follows:—

		Feet.	Inches.
North wall	East end,	0·630 =	7·560
	West end,	0·775 =	9·3
South wall	East end, ...	0·175 =	2·1
	West end, ...	0·265 =	3·18

The difference of settlement of the two walls is very remarkable, and rather embarrasses the basing of sound conclusions on the results.

The only causes to which this difference can be attributed are the three following:—

1*st*. Inequality in the consistency of the soil in the trenches.

2*nd*. Inequality in the protection of the two walls from the lodgment and infiltration of water.

3*rd*. The greater pressure on the north wall as the experiment progressed owing to the tilting of the load.

For the great care and precision observed in starting the work, which Lieut. Greenstreet so fully relates, prevents my supposing that any difference as to the width of the trenches and possible bulging up of the soil or any other special reason was at work in the case of the north wall.

The last of these three causes, however, can only be admitted into the question at the more advanced stages of the experiment, after uneven settlement had commenced, and had gone on to a considerable extent. And, further, it is apparent that this additional pressure could not have been large, as the cross strain that would otherwise have been brought on the slender walls by such a load would have turned the walls over.

The explanation of the difference must be referred then to the two first causes. That there is a variability in the character of the soil, owing in places to a greater proportion of loam, has been shown by the numerous excavations that have been made. It must be inferred therefore that the soil below the north wall had more of this loamy character, and that as might have been expected, the less efficient drainage round the wall, as Lieut. Greenstreet explains, operated additionally in weakening the sub-soil. In a measure also the same may be inferred regarding the west end of the south wall as compared with the east end of the same wall.

Still Lieut. Greenstreet represents the inferiority of drainage as but a comparatively trifling matter. And the conclusion finally to be accepted is, that in some parts of the plateau there are patches of subsoil, the bearing power of which is as small as that indicated by the worst of the tabulated results.

I regret that owing to the uneven settlement of the walls, it was necessary to stop the experiment, (although my exact order had been complied with), for it would have been interesting to know with what ultimate load the settlement might have ceased altogether. As the record stands—*vide* table of increments due to successive loads, and annexed table prepared by me, showing at each stage the amount of compression per ton of load—it is difficult to come to a conclusion on this point.

The figures indeed seem to show that the two walls should be considered separately. Thus, in the case of the north wall, east end, making the total compression obtained with a load of 2·73 tons per superficial foot, a starting point, the addition of 3 tons per superficial foot (nearly)* increased the settlement by 0·325 feet, or from 0·025 to 0·350, and the further addition of 2·16 tons per superficial foot caused a further settlement of 0·275. Considered proportionally, this shows a still increasing rate of compression; whereas the compression per ton of load shows a comparative decrease. In the first stage the increase was from 0·00918 to 0·05993 = say 0·058, and in the second stage from 0·05993 to 0·07875 = 0·018. This might argue perhaps that the limit of compression was being approached.

And the same might be argued from the figures relating to the west end of the same wall, where the whole compression increased in the first stage 0·350, in the second stage 0·395, and the compression per ton of load only increased as follows:—

In the first stage, ...	0·054
In the second stage, ...	0·031

On the other hand, the south wall, whichever end be considered, shows that with a load of 5·84 tons per superficial foot, scarcely any appreciable compression occurred, beyond what was noticed with a load of 3·857 tons,

* Exact figures 2·73
5·84

and that the compression per ton of load (as would necessarily result) decreased. The whole compression too, taking the worst point of the wall, was only 0·105 with the load of 5·84 tons per superficial foot, an amount that would not perhaps be considered objectionable.

After this point a higher rate of settlement is noticed, whether the total of compression be regarded or the compression per ton of load. But eventually the greatest settlement under a load of 8 tons per superficial foot did not amount to more than 0·265 feet or 3·18 inches, or 0·03312 feet per ton of load.

To deduce from these figures a rule for practice, it seems necessary to decide what should be the utmost settlement allowed within the limit of stability, and the further factor for safety that should be allowed in accordance with the general rule applicable to other portions of a structure.

If the limit for settlement were called three inches, and the factor of safety four, the record pertaining to the south wall would give 8 tons per superficial foot as the ultimate bearing power of the soil, and 2 tons per superficial foot as a safe working load.

If the limit were called two inches and the factor for safety as before four, the ultimate bearing power would be 6·765 tons, and the safe working load 1·691 tons per superficial foot. This, however, is taking the most favourable view of the case.

If the north wall be considered, and the same data be assumed, the results would be—

For a three-inch limit of settlement, about 5·4 tons per superficial foot the limiting load, and 1·35 tons per superficial foot the safe working load.

For a two-inch limit of settlement, about 4·72 tons the limiting load, and 1·18 the safe working load.

Or further, if one inch were the limit of settlement, the result would be—

As deduced from south wall	5·184	tons	limiting load.
	1·296	,,	safe working load.
As deduced from north wall	3·857	,,	limiting load.
	0·964	,,	safe working load.

Finally, if some allowance be made for the possible disadvantage under which our experiments laboured in having so thin a wall to be operated on, and some credit be taken for the better drainage arrangements that would be insured in the case of a building, it may be reasonable to adopt the mean of the foregoing results as a rule for guidance in fixing the safe load to be allowed.

With three inches of settlement as the limit $\frac{2 + 1{\cdot}35}{2} = 1{\cdot}67$ tons.

" two " " " " $\frac{1{\cdot}691 + 1{\cdot}18}{2} = 1{\cdot}435$ "

" one inch " " " $\frac{1{\cdot}296 + 0{\cdot}964}{2} = 1{\cdot}13$ "

The first result is slightly beyond the extreme limit (3·500 lbs.) mentioned by Rankine for a clay soil. The other results fall between the limits mentioned by him.

Experiments on compressibility of soil at Moradabad.

Load per superficial foot	NORTH WALL				SOUTH WALL				Remarks.
	EAST END		WEST END		EAST END		WEST END		
	Whole compression	Compression per ton of load	Whole compression	Compression per ton of load	Whole compression	Compression per ton of load	Whole compression	Compression per ton of load	
Tons	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	
2·730	0·025	0·00918	0·030	0·01101	Not	given.	Not	given.	
3·857	0·075	0·01944	0·085	0·02203	0·055	0·01426	0·075	0·01944	
5·184	0·205	0·03954	0·215	0·04147	0·065	0·01254	0·095	0·01832	
5·840	0·350	0·05993	0·380	0·06507	0·065	0·01113	0·105	0·01798	
6·303	Not	given.	Not	given.	Not	given.	Not	given.	
6·765	0·415	0·06134	0·475	0·07022	0·100	0·01478	0·160	0·02365	
7·647	0·525	0·06865	0·635	0·08304	Not	given.	0·225	0·02942	
7·764	0·545	0·07020	0·675	0·08694	0·125	0·01610	0·245	0·03156	
8·000	0·630	0·07875	0·775	0·09687	0·175	0·02187	0·265	0·03812	

Æ. P.

Continuation of Report by LIEUT. W. L. GREENSTREET, R.E., *dated 25th October*, 1873.

On the 13th October the whole of the load had been taken off the walls, and the levels could therefore be accurately taken by erecting the levelling staff at the four corners of each wall. The following table shows the result of the levelling :—

	Back	Fore	Rise	Fall	Reduced level	Original reduced level	Subsidence	Average subsidence for each wall
Reading at point G on plinth of No. 2 barrack, ...	2·285	..	..	...	655·18			
South wall (south-west corner)	..	4·825	..	2·54	652·64	652·915	0·275	·225
" (north-west ")	..	4·865	..	2·58	652·60	..	0·315	
" (south-east ")	..	4·685	..	2·4	652·78	..	0·135	
" (north-east ")	..	4·725	..	2·44	642·74	..	0·175	
North wall (south-east ")	..	5·17	..	2·885	652·295	..	0·620	·702
" (north-east ")	..	5·22	..	2·935	652·245	..	0·670	
" (north-west ")	..	5·33	..	3·045	652·135	..	0·780	
" (south-west ")	..	5·29	..	3·005	652·175	..	0·740	
Closing on G, ...	2·285							

By comparing this table with that formerly submitted, it will appear that the average subsidence for each wall is almost exactly the same as that formerly reported.

In order to examine the walls and the clay, the earth which had been laid against them, and sloped away from them so as to give better drainage during the rains, was removed, and the old surface of the ground laid bare. I could not discover any appearance of the soil having bulged upwards from below, and from experiments afterwards made, there does not appear to be any reason for supposing that there would be any bulging due to displacement. For there does not appear to be in the clay any tendency to follow the hydrostatical law of equal distribution of pressure; moist clay which has been *pugged* would of course do so; but the undisturbed clay appears to compress under pressure without distributing the force far.

Trenches, 2 feet wide, were dug across the centres of the walls, in order to admit of an examination of them being made.

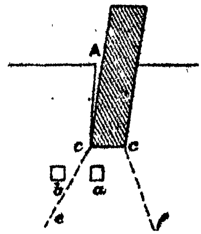
When thus opened out, the lower part of the walls appeared to be uneven. This was found to be due to the squeezing out of the mortar from the mortar joints in building the walls. When a brick is hammered on its bed, the mortar, of course, always squeezes out of the bed joint, and is caught up by the trowel; but in building this wall there was no room to take up the mortar thus squeezed out, which was therefore pressed out into the vertical sides of the foundation trench. It might be supposed that there would be no room for such squeezing out if the foundation trenches were true and of the same size as the wall, and yet the foundation trenches were laid out with great care, and I believe as accurately cut as they could be made, any irregularities being punned with clay. The explanation seems to be that the sides of the excavation were moistened with water used to flush the masonry, and, being thus softened, admitted the mortar pressed out of the masonry joints.

I carefully plumbed the walls when they had been cleared of the irregularities due to the mortar adhering to the side as explained above, and found that they both had the same batter, viz., 2½ inches in 4½ feet, or 1 in 21·6, which is rather more than was calculated in the former report.

There does not appear to have been any bulging in the walls under the heavy weight to which they were subjected.

There are several slight irregularities in the brickwork, but these do not appear to be due to bulging, but to the difficulty in building a wall perfectly plumb and even, when the sides cannot be seen or a plummet applied.

Neither of the 1½-inch Agra stone wall-plates were broken across, though one of them was slightly chipped at the edge, probably in consequence of some uneven strain.



Both walls on leaning over to the north left the clay sides of the cutting on the south side, and in the cracks or open spaces thus formed, the sand and earth put up against the walls to give drainage, were washed down during the rain, thus filling up the crack.

The space A as shown in the exaggerated sketch, is what is alluded to.

The ground when opened was very soft and damp. I could push a thin cane into the soil about 9 inches. There appears to be a layer of yellowish marly clay about 3 feet down. It is difficult to distinguish exactly where it begins, though there is a marked difference between the clay at a depth of 1 foot and 3 feet.

The clay is very soft and pliable when damp, although very hard when dry; but the trench was very damp, and therefore the wall which first descended furthest into this clay would have a better chance of descending still further than the one which had not begun, or had only just begun to enter it.

This perhaps may account for the difference of levels of the two walls; the north wall may have received its first *advantage* by the slight inferiority of its position as regards drainage, and may thus have been enabled to enter first and furthest into the more pliable yellow clay—an advantage which would tend to its still further unequal descent on the increase of pressure due to the additions of the load.

In order to ascertain how much the clay would shrink when subjected to a heavy pressure, I had a piece of hitherto undisturbed clay taken from between the two walls at a depth of 3 feet 3 inches, that is, at the depth of the present bottom of the north wall, and at a distance of 3 feet from the north wall. This was a piece of the yellow clay already mentioned.

This yellow clay has streaks of a red colour and little lumps of a softish dark brown substance in it.

This piece of unbroken clay was cut to the exact size of an iron brick-mould $9\frac{7}{8}'' \times 4\frac{7}{8}'' \times 2\frac{3}{4}''$; its volume therefore was 132·3 cubic inches. The unbroken piece of earth exactly filled this mould. It was placed on a flat board, and another flat board about an inch thick exactly fitting the mould was put on the top, and pressed down into the mould, thus gradually compressing the clay.

The pressure was obtained by means of a blacksmith's screw-vice. The amount of compression was $9\frac{7}{8}'' \times 4\frac{7}{8}'' \times \cdot 335$ cubic inch $= 16$ cubic inches, or the amount of volume lost by compression was $\frac{16}{132} = \frac{4}{33} = \frac{1}{8 \cdot 2}$ (or nearly $\frac{1}{8}$) of the original volume. And the area under compression was 48· square inches $= \frac{1}{3}$ square foot.

As it appeared probable that the density of the compressed earth would differ from that of the uncompressed, it occurred to me that something might be learnt by weighing different pieces of the clay with the edges and sides properly cubed, and the lengths of the faces measured.

I therefore cut from underneath the north wall, a lump of clay (at A), and cut it down carefully to the following dimensions $3\frac{3}{32}'' \times 4\frac{9}{16}'' \times 3\frac{7}{64}''$ $= 43 \cdot 889$ cubic inches; this lump of clay weighed 3 lbs. $3\frac{1}{2}$ oz. $= 51 \cdot 5$ oz., which divided by 43·889, gives 1·173 oz. per cubic inch. Another piece of clay (b) was taken at the same depth, and about one foot away from the wall, and was cut square, weighed and measured as before.

The result was as follows:—

Measurement.

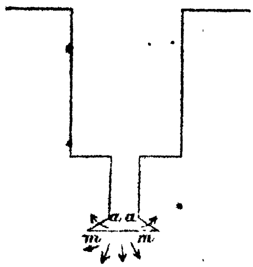
$5\frac{3}{16}'' \times 3\frac{1}{4}'' \times 3\frac{11}{32}'' = 56 \cdot 37$ cubic inches, and the weight was 60·125 oz. $\therefore \frac{60 \cdot 125}{56 \cdot 37} = 1 \cdot 066$ oz., *i. e.*, weight per cubic inch of this clay. Hence assuming that the densities are as the weights.

Density of compressed earth : density of unpressed earth :: 1·173 : 1·066 :: 10 : 9·08 :: 10 : 9 very nearly,

which nearly corresponds with the ratios of the volume of uncompressed earth to the compressed when pressed in a vice as above explained. In this case the volumes were as 132 : 132—16, or 132 : 116, or 10 : 8·8.

From this it appears probable that the clay at the points c and c might be slightly under compression, due to lateral pressure, but that the chief compression is vertically below the walls, though probably covering a gradually expanding area, as the *toughness* of the clay and its opposition to being *cut through* would tend to distribute the pressure—*vide* lines *ce*, *cf*, An experiment made a short time ago with reference to earth testing appears to throw light upon this point.

A hole 4 feet deep and 4 feet in diameter was dug 110 feet away from the site of these experiments and rammed; afterwards a small hole, about 7¾ inches diameter, was dug in the centre of the first hole 9 inches deep and rammed with an iron rammer which just fitted the hole. After ramming for 20 minutes, the bottom of the small hole had subsided 1¼ inch, and a crack all round the bottom of the hole was observed (at *a a* in the sketch), from which it appears from the toughness of the clay was sufficient to draw down the portions *m m* away from the upper portion of the sides of the hole—a result which is probably the opposite of what might be expected, namely, the upward pressure of the clay at the points *a a* due to the displacement caused by ramming, and this was why in the beginning of the report it was affirmed that the clay when it has its natural lie and bed does not appear to have any tendency to obey the hydrostatical law of the equal distribution of pressure.



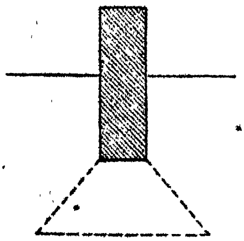
In order to judge, if possible, how far the earth, not under, but in line with the bottom of the wall, was under pressure, it is necessary to compare the weight of the piece already taken from this position (1·066 oz. per cubic inch), with the weight of a piece out of all possible range of the pressure, and with this object a piece of clay was taken from about half way between the two walls, and that the depth of 2½ feet below the ground, or the original height of the bottom of the walls; the piece when cut square was 108·02 cubic inches, and weighed 7 lbs. 3 oz. = 115 oz., ∴ $\frac{115}{108 \cdot 02} = 1 \cdot 064$ oz. per cubic inch, *i. e.*, the weight per cubic inch of this piece—a result which differs so little from the other as to lead to the conclusion that the former piece like the latter was not in a state of compression; another piece of clay was afterwards taken a little below the one at depth of 2 feet 6 inches, and with almost the same result.

The question remains what became of the earth when subjected to the pressure of 8 tons per square foot, and where did it go to?

Supposing first that only the earth vertically below the wall was compressed, then allowing a compression of $\frac{1}{8}$ its volume for every cubic foot, in order to obtain ·75 of a foot total vertical compression, the depth to which this compression would reach would be $9 \times {\cdot}762 = 6{\cdot}3$ feet, or as the wall is one foot wide, the sectional area under compression would be 6·3 square feet.

Of course the supposition of the compression taking place only vertically under the wall, is merely made for the purpose of illustration; and as the amount of compression would be gradually diminished as the distance from the wall increased, the actual sectional area under compression would be probably considerably greater than 6 square feet.

Assuming, however, that it would be 6 square feet as above, and that the earth under compression would take a pyramidal shape (*see* sketch) (with the sides inclined 45° to the vertical) in consequence of the distribution of pressure due to the toughness of the earth, if x be the depth of the bottom of this triangular portion below the wall, thus— $x\ (x + 1) = 6$, and solving the equation $x + \frac{1}{2} = \frac{5}{2}$; $x = 2$.



The real history of the compression probably lies somewhere between these two extreme hypothetical cases, and might be represented roughly by the sketch, the first few inches of compression being obtained by the sides of the wall cutting through the clay, and the further amounts by the compressions distributed over a larger area by the toughness of the clay.

I give these suggestions as to the manner in which the compression takes place in the clay as they occur to me; they will of course be taken for what they are worth. In so far as they are theoretical, they are proably not of much value, but they may serve to aid the conclusions of those wide experience fits them to theorize with authority.

As it may be interesting to know the amount of pressure under which the clay was found to lose one-eighth its volume by compression when pressed in a vice, I give the following calculation:—

Pitch of screw $\frac{7}{16}$-inch.

Length of lever arm $1\frac{1}{2}$ feet.

Diameter of screw $1\frac{3}{4}$ inch.

I estimate the force I exerted on the lever arm as about 100 lbs. = P, allowing only for the friction exerted between the threads of the screw—

* $P \frac{a}{r} = Q \tan (L + Q)$; where L is the inclination of the screw, Q the uniting angle of resistance*—

a = lever arm of P.

r = radius of screw.

$$L = \tan \frac{-1 \text{ pitch}}{\text{circumference}} \text{ of screw} = \tan^{-1} \frac{\frac{7}{16}}{4 \cdot 5} = \tan^{-1} = \cdot 081 = 5^\circ.$$

And the value of Q for iron against iron is about 10°.

$$\therefore P \frac{1 \cdot 5 \times 12}{\frac{7}{8}} = Q \tan (5^\circ + 10^\circ)\ 100 \times \frac{144}{7} = Q \tan 15^\circ \therefore Q = \frac{100 \times 144}{7 \tan 15^\circ}$$

Log 100	=	2
,, 144	=	2·1583625
		10
		14·1583625
Log 7	=	·8450980
,, tan 15°	=	9·4280525
		10·2731505
Log Q	=	3·8852120 Q = 7647·6 lbs. = 3·4 tons.

Say 3 tons to allow for the other surfaces under friction not taken account of in above formula, and this force was brought upon $\frac{1}{3}$ square foot, and would, therefore, represent 9 tons per square foot.

W. L. G.

Note by Colonel Alex. Taylor, R.E., *Chief Engineer, Military Works.*

This is a very interesting report. The experiment was well devised and has been carefully carried out and fully reported.

The experimental ramming referred to in Lieut. Greenstreet's report was calculated—

(*a*). To demonstrate clearly that in the several stations in which large building operations have to be carried out by this branch, the resisting powers of the soil differ greatly.

(*b*). To establish also that similar differences occur in the same station.

(*c*). To bring home to all concerned, the importance, in the case of all buildings, of consolidating the soil at the bottom of the foundation trenches to the full extent that can be effected by hand ramming before laying the foundations of the walls.

Attached to this note is given the result of the experiments so far as they have been reported.

* Tulsden's Practical Mechanics.

It will be seen that it was not found to be practicable at Moradabad to effect much compression of the soil in this way, showing its powers of resistance to be greatly in excess of that at Fyzabad and Allahabad. This should be clearly borne in mind in attempting to deduce, from the experiments now reported, a safe load for future adoption.

The most remarkable fact which the experiment brings to light is the very great difference in the bearing power of this strong soil in the very small area of 9′ × 6′ (*see* Lieut.-Col. Perkins' letter). Under the load of 8 tons per square foot, the compression varied from 2·1 inches to 9·3 inches, and this under circumstances eminently calculated to secure an even settlement. It is clear from the report of the Executive Engineer, that neither the appearance of the soil, nor the information in regard to its quality, which he acquired from having it punned for two days with heavy rammers, led him to anticipate that its bearing powers were so inferior under the north wall generally, and so greatly inferior under its west end.

The next point to be kept in mind is, that the experiment extended over a very small period of time. The loading was commenced on the 12th July, and unloading was entered on the 16th September, 1873. There can be no question that had the loads been allowed to remain in force for a long time, very greatly increased movements would have resulted. This will probably be accepted on all hands; but there is no want of large buildings to be referred to in which for some years after their completion there were no cracks or signs of movement, but which afterwards began to subside irregularly, and exhibit rents more or less unsightly and causes of anxiety.

To me it seems Lieut.-Col. Perkins' letter establishes sufficiently that in the case of the strong soil of Moradabad, it would not be prudent to load the foundation trenches of a long building with a greater weight than 0·964 tons per square foot, for it has not been ascertained that the soil on which the experiment was made, represents fairly the weak parts of the Moradabad surface, and it is shown that that is a load which would be only suitable to the soil experimented on, if its action were limited to a short space of time.

From a consideration of the foundations of many existing buildings, some of which are obviously much too narrow, and others of which are perhaps nearly sufficient, I am satisfied that in our plain stations, such as

Cawnpore, Allahabad and Fyzabad, it is not prudent to place the main walls of double-storeyed barracks on foundations of less width than 9 feet, and this after effecting all that consolidation of the bottom of the foundation trenches that can be produced by hand-ramming with heavy pavior rammers.

The pressure on the soil under the foundations which will then obtain, taking the maximum vertical wind pressure at 25 lbs. per square foot, and the load on the upper floor at 90 lbs. per square foot, will be about the amounts shown in the margin, which have been calculated from designs for a building, of which the lower walls are 2¼ feet thick and 17 feet 6½ inches high; and the upper walls 1 foot 10½ inches thick and 20 feet high to the bottom of the tie-beam.

	Including a load on the upper floor of 90 lbs. and a vertical wind pressure of 25 lbs. per square foot.	Omitting load on floor and all wind pressure.
Load on the foundation trenches of main wall in tons per square foot,		0·73

Reported result of experiments made on the compressibility of the soil in certain Stations, at from 2½ to 4 feet below the surface, as tested by hand-ramming.

Name of Station.	Compression of the soil in inches.		Remarks.
	Least reported	Greatest reported.	
Fyzabad, ...	0·72	7·68	
Allahabad, ...	0·625	3·0625	
Cawnpore, ...	0·24	0·84	
Moradabad, ...	0·24	1·08	
Ráwal Pindi, ...	0·36	0·72	

Note by Major-General Alex. Taylor, *Offg. Secy. to Govt. of Punjab, P. W. Department.*

It is observed that in the conclusions arrived at in Bengal in regard to the weight that may properly be placed on foundation trenches in the alluvial soil of that Province,* a factor for safety has no place. It is practically assumed—

(a). That the compression which was reached in a few days would not be materially increased were the load allowed to act for years.

(b). That the soil at Acra, at the precise place where the experiments were made, is not superior in its power of supporting a load to the alluvial soil of Calcutta or other parts of Bengal.

On the other hand, the Moradabad experiment shows conclusively that at that station, (where the soil is of a most excellent and firm character,) the ground yields under pressure exceedingly unequally, even in places only a few feet apart.

The table at the foot of the note by the Chief Engineer, Military Works, also shows that in different stations the power of soil to resist pressure differs greatly; while the history of numerous large buildings in Northern India, clearly establishes that foundations which have satisfactorily carried them for a considerable period have in time yielded, and caused very serious rents in the walls.

In supersession of former orders, it is directed, as regards this Province, that in soil which admits of being consolidated by ramming, the foundations be always thoroughly punned with heavy rammers, and the load on them limited to ¾ths of a ton per square foot.

A. T.

* *Vide* No. CLXXI., Professional Papers on Indian Engineering, Second Series.

No. CCXXXIV.

GANGES RIVER TRAINING WORKS OF THE LOWER GANGES CANAL.

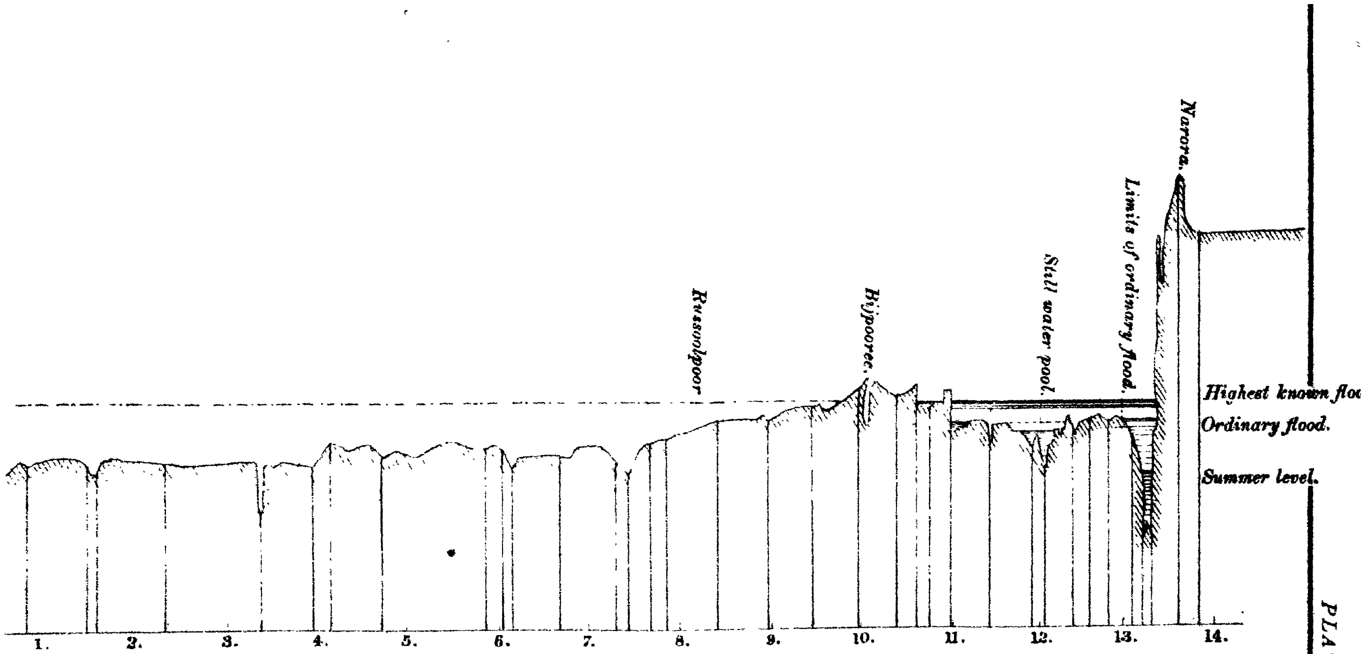
[*Vide* Plates XXXI., XXXII. and XXXIII.]

BY MAJOR H. HELSHAM JONES, R.E.

THE works which it is proposed to describe in the present paper are situated on the left bank of the Ganges between Rajghat and Narora. Rajghat is the place where the Oudh and Rohilkhand Railway crosses the Ganges between Aligarh and Chandausi. Narora is four miles below Rajghat, and is the site of the weir intended to turn the waters of the Ganges into the new canal called the Lower Ganges Canal.

The works in question were designed to serve a double purpose; viz., *first*, to straighten the course of the river, which before their construction was very crooked, and *secondly*, to prevent the flood waters of the Ganges, when raised above their natural level by the construction of the weir, from finding an outlet over the low country on the left, or eastern bank, and outflanking the weir altogether. That this latter danger needs to be guarded against even more than is generally necessary in such cases, will be seen on an inspection of the cross section of the Ganges valley given in *Plate* XXXI. It will be observed that the present course of the stream is by no means in the lowest part of the valley, but that a few miles to the eastward, there is an old bed on a much lower level than that in which the river now flows. Should the river break out to the east, it might lead to an entire diversion from its present course, or at any rate an enormous amount of damage might be done by the flood waters pouring down into

CROSS SECTION OF THE GANGES KHADIR AT NARORA.



the low country. Such an event did occur somewhat higher up the river a few years ago, but the present writer is not aware of the precise position of the outbreak, nor of the details of the event. The water which then escaped from the present course of the Ganges did much damage in the low level bed (known as the Mahewar Nadi) to the eastward. It is understood that some measures to prevent a recurrence of the disaster were taken; whether sufficient or not remains to be seen. At any rate, it is quite clear that such an event occurring in the neighbourhood of the weir, would be highly dangerous and this was one of the reasons urged in 1872, by Lieut.-Colonel Henry Brownlow, (then Offg. Chief Engineer,) against a reduction of the length of the Narora weir from 4,000 to 3,000 feet, as proposed by Colonel Rundall.

In order to serve the double purpose above referred to, the works consist of two parts :—

1. An embankment running along the edge of the khadir land, called the left embankment.
2. A system of groynes placed at right angles to the lateral embankment and projecting into the river; serving to drive the stream over, and subsequently to keep it from returning to its former course, and endangering the embankment.

Plate XXXII., *Figs.* 1 to 6, will render the description intelligible.

Fig. 1 shows the condition of the river in 1870, when the first project for the canal was being drawn up.

Fig. 2 shows the course of the river in the spring of 1873, when the works were begun,* and the remaining figures show the state of the river in the beginning of each succeeding year up to the present time.

Combined with the permanent works tree spurs have also been used, and in some instances very successfully. They are, however, only temporary expedients and cannot, unsupported by other works, be expected to secure permanent results.

The right bank of the river is high and permanent, being composed chiefly of strong clay, and it is strengthened by beds of kankar which are found at the headlands of Karanbas, Rajghat and Ramghat. The present left bank is low and composed of sand, and the actual left bank of the Ganges valley is 12 to 14 miles to the eastward. No doubt the river has at different times wandered between these wide limits.

* The weir works were begun in March 1873.

It will be seen (*Fig.* 1) that in 1870 the river ran close under the high bank off the village of Nayabas, (above Rajghat,) forming a deep bay, and that it then crossed the river and formed a deep bay on the left bank of the village of Faridpur. Before 1873 there had been a great improvement. This was partly due to the tendency, well-known in these rivers, of deep bays to silt up of themselves, partly to the works of the Oudh and Rohlikhand Railway. At first sight the railway embankment thrown up in 1869-70 seems as if it would have acted as a groyne, but in fact the flood waters did not reach it. It, however, closed several minor channels on the left, or east bank, and a number of brushwood spurs, which were used to train the river at the site of the railway bridge had also a good effect. The conditions were, therefore, more favourable when the works were begun in 1873, than they would have been had it been necessary to begin in 1870.

Fig. 2 of *Plate* XXXII., shows the state of the river in 1873. The Nyabas bay was then to a great extent dry, and the course between Karanbas and Rajghat tolerably straight, but there was a great loop between Rajghat and the village of Narora, and at its apex the bed of the river was a mile-and-a-half east of the course desired. There was also a side channel (not shown on the plan) following the course of the stream of 1870. This did not run in the cold weather, but there were pools of water along its course.

The works proposed in 1873 were—

A part of the left embankment from the railway bank near Miranpur to the root of No. 2 groyne. Also three-quarters of a mile of the embankment from the left flank of the Narora weir upwards.

Two groynes Nos. 1 and 2.

A tree spur just below the Rajghat railway bridge.

These are shown in dotted lines on *Fig.* 2 of *Plate* XXXII.

The embankment was laid out so as to keep on firm soil, and its alignment was thrown back 1,000 feet to the east of the left wing of the Narora weir, so as to keep it clear of heavy scour during floods. The top of the bank was fixed 5 feet above the probable H. W. M. of floods, after the completion of the weir.*

The top width 15 feet with front and back slopes of $\frac{1}{2}$ and $\frac{1}{3}$ respectively.

* This is a matter which it is almost impossible to calculate correctly, and the top level may need be raised. This can be ascertained as the weir is gradually raised to full height.

The groynes were designed with their top level the same as that of the embankment at the point from which they spring. Top width of 10 feet (subsequently increased to 15 feet), and both side slopes $\frac{1}{3}$. No. 1 was 2,800 feet in length, No. 2 about the same.

Of these two groynes only No. 1 was sanctioned, as the short time remaining before the floods did not allow of both being made. Indeed, No. 1 was only got up with great difficulty amidst the furious hot winds which prevailed in that season. The expedient of using screens of arha had to be resorted to, to get it up at all. These screens were set up along the line, and the bank brought up three or four feet under shelter of them. They were then set up on the top of the bank so formed which was again raised as much as possible, when a second move was made, and so on. The groyne consisted of pure white sand, nothing else being available. The thin deposits of mud usually found in these rivers, and which serve to cover the surface after the section is formed, were not to be found, and it was necessary to collect grass roots and put them in on the up-stream slope and to keep up the arha hedge for the protection of the crest. In the next season these mud deposits were found in the bay formed by the groyne, in sufficient quantity to soil the whole of it effectually.

There was no difficulty in constructing the main lateral embankment. The ground to be covered by the bank and that used for borrow pits, was carefully stripped of its turf and alluvial soil, and the material so obtained was preserved for soiling the bank, and in most places was sufficient.

The head of the groyne was made on the plan described in the 2nd Vol. of the Roorkee Treatise on Civil Engineering, as having been used on the Gandak, and which is shown on *Plate* XXXIII. The stakes were driven 12 feet below low water. They were driven by means of the Swiss pile driver, described by Lieut. T. J. Bucknill, in the 18th Vol. of the Professional Papers of the Corps of Royal Engineers. These pile drivers have been largely used on the Narora works, and found very useful. In 1875, however, some light wrought-iron ringing engines which had been used at Narora were available. They were used and did the work much more quickly. They are provided with movable beds and flanged runners, so that they are very easily moved. With the Swiss piler, a good deal of time is lost in getting the pile set up truly.

The space between the double lines of stakes was filled with block kankar alternating with fascines in beds, two feet thick of each. The fascines were made of tamarisk (*jhāo*) jungle cut near the river, and made up precisely like those used in field fortification. The block kankar had to be brought by railway from near Aligarh, and carted from Rajghat. It was therefore costly, and one of these groyne heads can not be made here much under Rs. 12,000.

A tree spur was made, resting on the east abutment of the railway bridge, and extending 1,200 feet in the direction of the village of Nodai. It was hoped that this spur would divert the early floods into the channel passing Nodai. It did not effect this, possibly because there was a clay bank leading to the temporary railway bridge which had a contrary effect, and this clay bank was not removed by the railway Engineers till May 1874. After its removal, the flow in this channel increased, though the tree spur no longer existed. This tree spur, however, greatly assisted the action of No. 1 groyne during the floods of 1873, and helped to throw the action of the flood on the large island.

There was a deep scour off the head of No. 1 groyne in July 1873, but the groyne head stood it admirably, though some repairs were needed. A Sub-Overseer and a party of men lived on the spot. At one time the flood swept round the groyne head and attacked the down-stream slope. This was met by using trees to protect the part attacked, and by a small tree spur attached to the down-stream side of the head.

Fig. 3 shows the result of the work done in 1873. It will be observed that the absence of the second groyne was a serious evil. The flood stream driven against the large island by the Rajghat spur and No. 1 groyne, re-bounded over the site of the proposed second groyne and settled into a cold weather stream further east than in the previous season at this part. Consequently the No. 2 groyne could not be carried to its full length in 1874. It could only be made 2,800 feet long.

In the cold season of 1873-74, the work done consisted of an extension of the left embankment to the root of No. 2 groyne; the construction of No. 2 groyne and of a tree spur 800 feet long attached to the head of groyne No. 1. It was hoped that this tree spur would cause the eastern channel to silt up, and allow the new groyne to be carried to the length proposed in 1873, but its action was not rapid enough for this, and the groyne has to be stopped at 2,800 feet, as above-mentioned. Later, when the floods began, it greatly assisted the action of No. 2 groyne. The head of No. 2 was precisely similar to that of No. 1 groyne.

It was at first intended to propose an extension of No. 1 groyne, but this idea was abandoned because, being intended to serve as a part of the permanent system of works, it was not thought prudent to advance the head too near to a line joining the left abutments of the bridge and weir. It lies about 1,400 feet clear of a line joining them, and the heads of the other groynes were retired to the same distance from this line.

In the early part of the floods of 1874, No. 2 groyne was exposed to a severe trial. The floods at first kept to the eastern cold weather stream and, as the last 300 feet or so of the groyne had the stream running nearly parallel to it, there was a severe scour. This was met by fixing trees along the face, and by a small spur of stakes and brushwood run out up-stream. Two cross spurs of sand (shown in *Fig.* 6), with heads of stakes, brushwood, and a little kankar, had been made, and prevented the water ponded up above from running along the face of the groyne. The down-stream one prevented any action similar to that on No. 1 groyne in 1873.* The flood, however, rushed round the groyne head with great force, and the lead frequently showed a depth of 40 feet quite close to the cribwork. The up-stream nose first subsided, thus performing its office.

Later (on 3rd July) the horse-shoe of cribwork was partly breached and part of the neck fell in, owing to the depth of water on the up-stream side, but the Sub-overseer (who lived on the spot) was able to prevent a complete breach between the head and the body of the groyne, by using trees, &c. A few days later the action of the groynes in silting up the bay between them began to tell and increased very rapidly, so that in August a small boat could not pass down what had been the main channel. Ultimately the cold weather stream receded to 3,600 feet east of the groyne head, as shown in *Fig.* 4.

Fig. 4, compared with *Fig.* 3, shows the erosion of the large island in the floods of 1874 to have been very considerable. Owing to the shortness of No 2 groyne, a point was left just below the prolongation of this groyne, and the deep stream was deflected towards the old hamlet of Gangabas, and then re-bounded in the direction of the right flank of the weir; leaving a large piece of land in front of the eastern part of the weir.

In the cold weather of 1874-75, No. 2 groyne was extended 1,800 feet, making a total length of 4,600 feet, and a new head was made, the

* This action occurred but merely caused some damage to the head of the cross spurs.

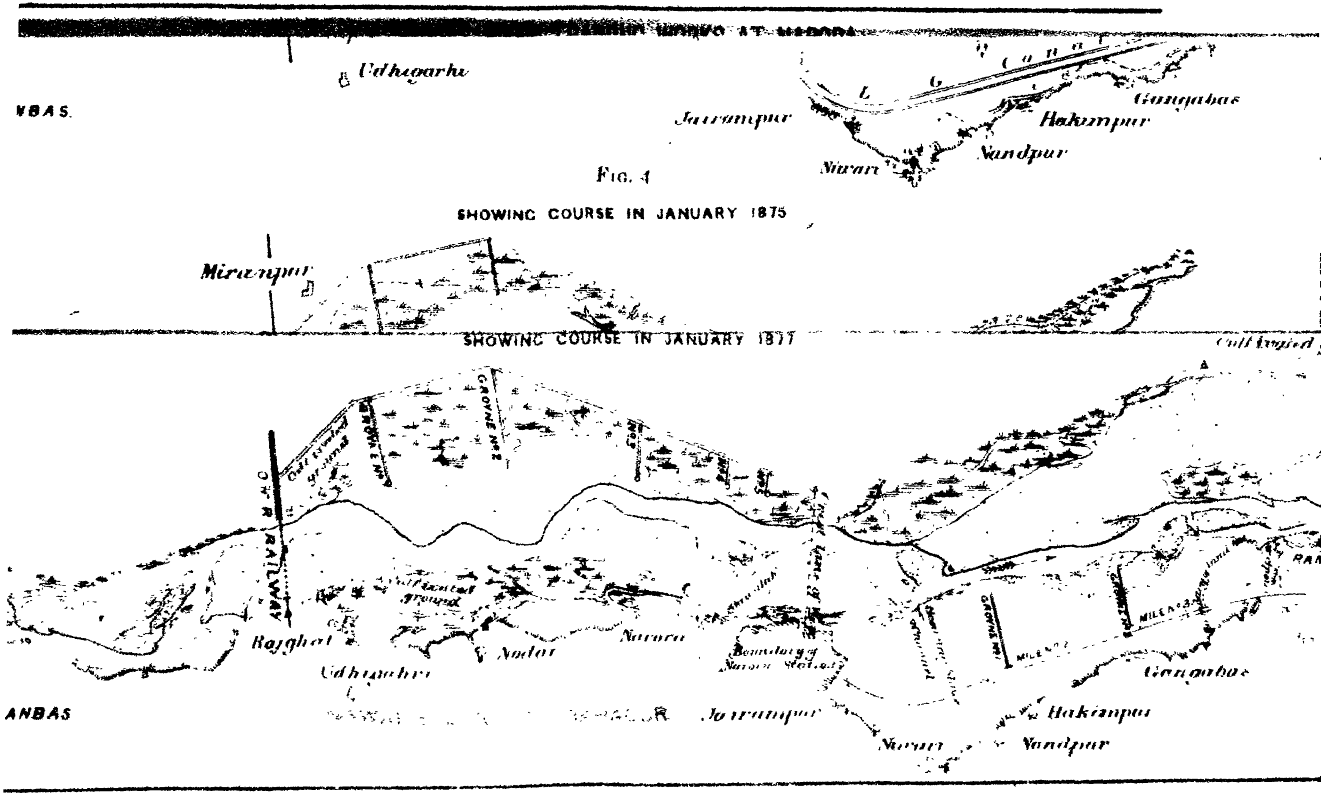
available materials of the old one being utilized. The main embankment was also extended as shown in *Fig.* 5.

It was expected that this extension of the groyne would cause the erosion of the island opposite No. 2 groyne to be considerable, and also cause the main stream to impinge near, and cut away the point opposite Narora village, and force the stream to pass in a nearly straight line from off No. 2 groyne to below the weir. This expectation was realized. A tree spur was used, attached to the new head of No. 2 groyne, and the combined action of these works was very rapid and effective. Long before the end of the floods, the Gangabas bay was getting dry, and the main stream impinged on the desired point, and by its action, aided by gangs of men who were employed to loosen the grass and roots on the bank, removed a large quantity of soil which would otherwise have had to be excavated. This saved a considerable sum of money, and, what was of more importance, allowed the stream to run in a straight course over the line of the weir. In previous seasons there had always been a set into the right bank above the canal head and weir sluices, and the water running out round the bund enclosing the sluices had scoured deep, and thus hindered the works Thirty feet of water had often been measured in the cold season at places where it was desired to lay kerbs and sink wells. At the beginning of the cold season of 1875, the river had, owing to its running in a tolerably straight course, assumed a very regular section with a moderate depth everywhere, was easily manageable, and offered no obstacle to an early commencement of work in completing the line of wells for the weir. This was accordingly taken in hand in October, and the line completed from bank to bank in March following.

In the season of 1875-76, the system of main groynes was completed by the construction of No. 3 groyne, in a way precisely similar to the others and by throwing out two small groynes Nos. 4 and 5 from the embankment near the left flank of the weir. These two last were intended to prevent any lateral-scouring action on the left embankment during floods. No. 3 groyne was required to secure what had been gained in the previous season, as well as to protect the left embankment. The embankment was also completed in this season.

In the floods of 1876, there was no very severe action on the groynes. The erosion of the main island continued, and was accelerated by keeping a large gang of men at work opposite groyne No. 2.

PLATE XXXII.


Udhigarhi
Jairampur
Gangabas
Hakimpur
Nandpur
Narori
Fig. 4
SHOWING COURSE IN JANUARY 1875
Mirzapur
SHOWING COURSE IN JANUARY 1877
Cultivated area
GROYNE No 2
GROYNE No 3
O. & R. RAILWAY
Cultivated ground
Rajghat
Nador
Narora
Boundary of Narora Station
Jairampur
GROYNE No 1
MILE No 2
MILE No 3
Gangabas
Hakimpur
Nandpur
Narori
RAMGH.
NBAS.
ANBAS

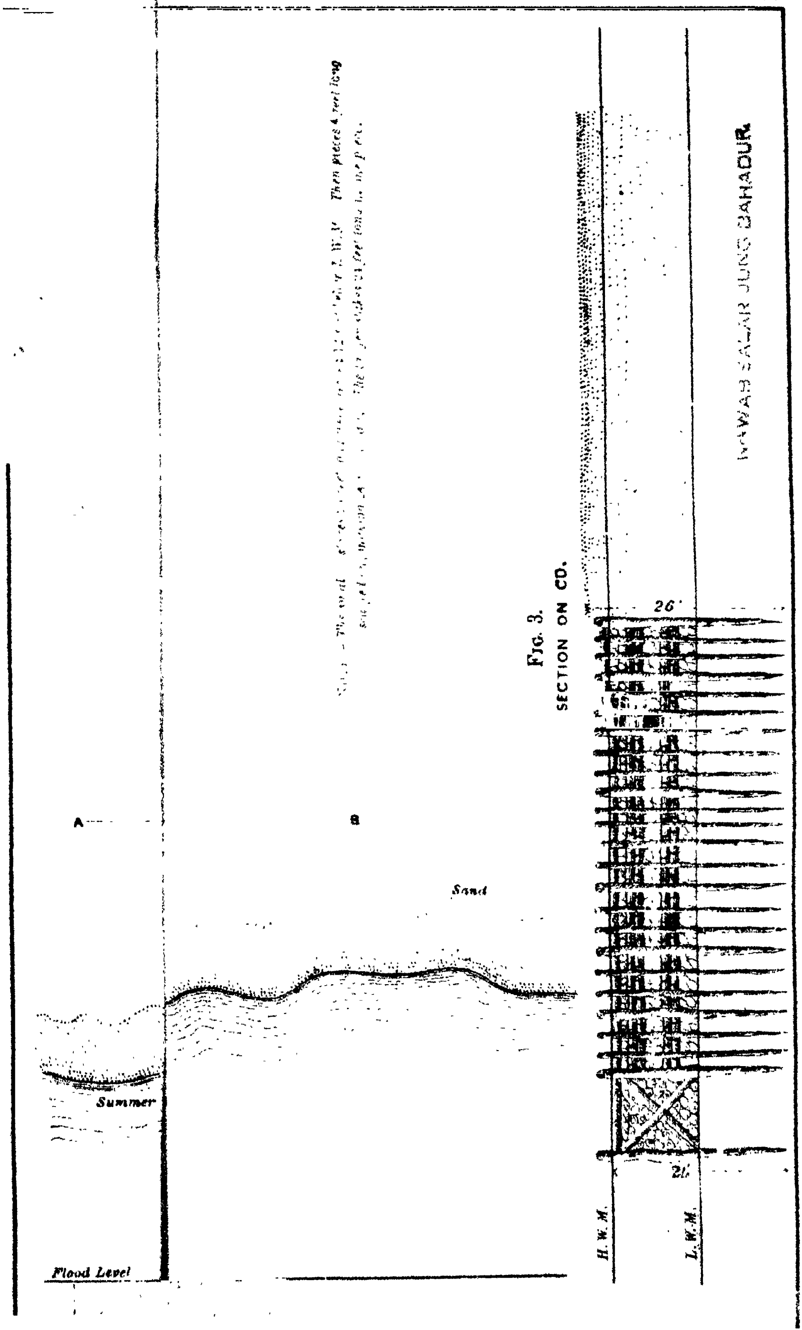


Fig. 3.
SECTION ON CD.

Cuts had been made during the cold weather to conduct the flood waters to the left or eastern part of the weir, and during the floods, gangs of men were kept at work loosening the soil, both above and below the weir, and thus promoting the scouring action through them, and also outside on the left bank of the old stream. The result is seen on comparing *Fig.* 6 with *Fig.* 5.

In the present season there remains nothing to be done to complete the system of works as at first proposed, but it is intended to throw up some small sand groynes between the main ones, to check the movement of water during floods and thus accelerate the silting up of the bays between the main groynes, which may be expected gradually to go on until the soil reaches the level of high floods, and is all covered with jungle. When this shall have been accomplished, the embankment will be well protected against scour, and it will only be necessary to keep it in repair and free from rat-holes, &c., to provide against extraordinary floods.

MEERUT,
10th March, 1877. } H. H. J.

No. CCXXXV.

DISCHARGE OF CANALS.

By Capt. Allan Cunningham, R.E., *Hony. Fel. of King's Col., Lond.*

[*Preface.*—In this Paper is embodied the experience gained in extensive Hydraulic Experiments performed under the writer's superintendence in cold season of 1874-75, and from December 1876 till the present time. It is published as a suggestion towards obtaining uniformity of procedure in Discharge-measurement on Indian Canals].

1. Discharge.—The measurement of the Discharge of a Canal actually running, is an element of prime importance in Irrigation economy.

In consequence of the approximate regularity of the beds of Canals, and of their comparatively small size, much greater accuracy is obtainable in the estimation of the Discharge of a Canal than of a large River.

Different methods are applicable according to the size of the Canal in question. For this purpose they are conveniently classed under the heads of "Small Canals" and "Large Canals."

2. Small Canals.—Experiments were made in France by MM. Darcy and Bazin for a great length of time on small experimental canals of about 6 feet width under such varied conditions of bed, banks, and slope, that the measurement of Discharge of small canals may now be made with considerable care and accuracy by help of their results.

The Results of their Experiments may be summed up in following formulæ:—

Let r = Hydraulic Mean Depth of any cross-section *in feet.*

A = Area of that cross-section *in square feet.*

S = Slope of water-surface at that cross-section.

= Fall of water surface in any distance $\div$ by that distance, both dimensions in same lineal unit, *e.g.*, *in feet.*

v_0 = Maximum (or Central) Surface Velocity at that cross-section *in feet per second.*

V = Mean Velocity through that cross-section *in feet per second.*

D = Discharge through that cross-section *in cubic feet per second.*

C, **c** are certain (variable) coefficients depending on the hydraulic mean depth and nature of banks and bed.

Then the formulæ are, $D = AV$, ... (1).

$$V = \mathbf{C}\sqrt{rS}, \text{ where } \mathbf{C} = \sqrt{1 \div \beta\left(a + \frac{1}{r}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2),$$

where a, β are certain numerical coefficients depending on the nature of banks and bed, whose values are given in Table I., for the four cases given by Darcy and Bazin.

$$V = \mathbf{c} \cdot v_0, \text{ where } \mathbf{c} = \frac{\mathbf{C}}{\mathbf{C} + 25 \cdot 3}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (3).$$

Thus the Discharge may be obtained by observations of two distinct kinds :—

(1) of slope (S), and hydraulic mean depth (r).

(2) of central surface-velocity (v_0).

Method i. (*Data* S *and* r.)—In small canals, the average slope of bed is (when uniform through a great length) very closely the same as the surface-slope, (except near the head, where the motion is not uniform): this permits of the "bed-slope" being used (for S) instead of the "surface-slope," (which is in strictness the quantity represented by S.) This enables an estimate of the Discharge that may be expected from a *given* small canal (in which of course the "bed-slope" and "hydraulic mean depth" are known) to be estimated *à priori* with some confidence,—a matter of considerable importance,—by use of formula (2).

When a small canal is actually running, observations of the actual "surface-slope" may be made, and this quantity may be used for S in formula (2), but the convenience and correctness of the other method following, (Method ii,) are so much greater. that this is seldom resorted to.

The value of **C** is given in Table I. below for values of $r < 20'$, so that only the quantity $\mathbf{C}\sqrt{rS}$ requires to be calculated for such cases. Even this labour may be saved in ordinary cases by the use of Tables* suited for the purpose.

* "Tables of Rájbaha Velocities and Discharges," by the present writer, showing values of V and D calculated by formula (2) for *earthen trapezoidal channels* for bed-widths 1′ to 20′, depths 1′ to 5′, and falls 0′·25 to 3′ in 5,000′. Three series have been published for side-slopes of 1½ to 1, 1 to ½, and 2 in 1.

Table I.

Values of C for use in formula $V = C \cdot \sqrt{rS.}$

Hydraulic Mean Depth in feet. r.	Value of C. Bed and Sides of fine plaster.	Bed and Sides of cut stone or brickwork.	Bed and Sides Rubble or Boulder Masonry.	Bed and Sides of earth.
·5	135	110	72	36
·75	139	116	81	42
1·0	141	118	87	48
1·5	143	122	94	56
2·0	144	124	98	62
2·5	145	126	101	67
3·0	145	126	104	70
3·5	146	127	105	73
4·0	146	128	106	76
4·5	146	128	107	78
5·0	146	128	108	80
5·5	146	129	109	82
6·0	147	129	110	84
6·5	147	129	110	85
7·0	147	129	110	86
7·5	147	129	111	87
8·0	147	130	111	88
8·5	147	130	112	89
9·0	147	130	112	90
9·5	147	130	112	90
10	147	130	112	91
11	147	130	113	92
12	147	130	113	93
13	147	130	113	94
14	147	130	113	95
15	147	130	114	96
16	147	130	114	97
17	147	130	114	97
18	147	130	114	98
19	147	130	114	98
20	147	131	114	98

General Value of C for use when $r > 20'$.

Bed and Sides of fine plaster, $$C = \sqrt{1 \div \cdot0000045 \left(10\cdot16 + \frac{1}{r}\right)}$$

Bed and Sides of cutstone or brickwork, $$C = \sqrt{1 \div \cdot000013 \left(4\cdot354 + \frac{1}{r}\right)}$$

Bed and Sides of rubble or boulder masonry, $$C = \sqrt{1 \div \cdot00006 \left(1\cdot219 + \frac{1}{r}\right)}$$

Bed and Sides of earth, $$C = \sqrt{1 \div \cdot00035 \left(\cdot2438 + \frac{1}{r}\right)}$$

Table II.

Values of c for use in formula $V = cv_o$.

Hydraulic Mean Depth in feet. r.	Value of c. Bed and Sides of fine plaster.	Bed and Sides of cut stone or brickwork.	Bed and sides Rubble or Boulder Masonry.	Bed and Sides of earth.
·5	·84	·81	·74	·58
·75	·84	·82	·76	·63
1·0	·85	·82	·77	·65
1·5	·85	·82	·78	·69
2·0	·85	·83	·79	·71
2·5	·85	·83	·79	·72
3·0	·85	·83	·80	·73
3·5	·85	·83	·80	·74
4·0	·85	·83	·81	·75
5·0	·85	·83	·81	·76
6·0	·85	·84	·81	·77
7·0	·85	·84	·81	·78
8·0	·85	·84	·81	·78
9·0	·85	·84	·82	·78
10	·85	·84	·82	·78
11	·85	·84	·82	·78
12	·85	·84	·82	·79
13	·85	·84	·82	·79
14	·85	·84	·82	·79
15	·85	·84	·82	·79
16	·85	·84	·82	·79
17	·85	·84	·82	·79
18	·85	·84	·82	·79
19	·85	·84	·82	·79
20	·85	·84	·82	·80

General Value of c for use when $r > 20'$.

$$c = \frac{C}{C + 25\cdot3}$$

Method ii. (Datum, Central Surface Velocity, v_0).—The sole observation required is a good measurement of the Central Surface-Velocity freed from the effects of time-variations. It will be found on trial that successive measurements of the velocity—even if succeeding one another, as rapidly as the means admit, and even with all precautions as to accuracy—differ considerably. This is to be attributed to a great extent to real changes* in the motion of the current, and not by any means to observation-error alone. What is wanted for the present purpose is evidently the average value of the central surface-velocity. As the calculated Discharge is to depend on the measurement of velocity at a single point, (the centre,) every pains should be taken to ensure obtaining a really good average value of this quantity freed from the effects of time-variations. At least 20 separate measurements (but the more† the better) should be made, and their arithmetic mean should be taken as the "average value of the central surface-velocity," being the quantity denoted above by v_0. The mean velocity may now be found by formula (3). ($V = \mathbf{c} . v_0$). The values of $\mathbf{c}$ for ordinary cases (according to Bazin's Experiments) are given in Table II.

The instructions as to *Site, Run, Cross-section, Timing, and Reduction of Velocity*, given in the following Article, in case of observations on Large Canals, are applicable to a great extent to the present case also.

3. LARGE CANALS.—The Discharge of these may also be *roughly* obtained by the same methods as above described for Small Canals, but with much greater accuracy by measurement of the "Mean Velocities" past a great number of verticals in the same cross-section, either with "Velocity Rods" or by "integration," (*see* Art. 125, Vol. II. of Roorkee Treatise on Civil Engineering, 3rd Ed.), with a Current Meter.

From a very extensive series of Experiments on the Ganges Canal at Roorkee, it has been established‡ that,—

> "The actual velocity of a floating thin vertical Rod reaching from the surface nearly to the bed, is very nearly equal to the "Mean Velocity" of the vertical plane in which it moves,"

the approximation being it is believed at least as great as is obtainable with any other instrument. Upon this sole principle, (established by

* *See* "Hydraulic Experiments at Roorkee in 1874-75," by the present writer, Art's. 23 to 25.

† The standard number used in the Hydraulic Experiments at Roorkee in 1875-77 was 48.

‡ The Experiments are still in progress, so that the full evidence on this point has not yet been published. There is some evidence to this effect in "Hydraulic Experiments at Roorkee in 1874-75"

Experiment) the application of these Rods to Discharge-Measurement depends. The rapidity with which this Result (the Mean Velocity in its line of motion) is obtained, far exceeds that possible by any other known process, except "by integration" with a Current Meter. The simplicity and cheapness of manufacture, and the convenience of use of the "Velocity-Rods" is so great, that their use will, it is expected, be generally adopted for Discharge-Measurement in Canals, and will alone be described here.

4. *Description of "Velocity-Rod."*—The essential requisites are:—

"The Rod should be round (cylindric), thin, stiff, of uniform exterior, non absorbent of water, and unaffected by hot winds; its centre of gravity should be *as low as possible*, and the part projecting above the water should be *as light as possible*."

The pattern used in the Experiments* at Roorkee, in which all the above requisites are secured in a high degree, is simply a hollow (cylindric) tube of about 1 inch diameter made of sheet tin: the lower portion (or loaded end) is formed round a short length of rod-iron, the diameter of which in fact determines the diameter of the whole tube; the length of iron used is such that its weight almost submerges the tube to the depth desired; the fine adjustment being effected by the addition of small shot by experiment in still water. About 2 or 3 inches is left projecting out of the water, and the mouth sealed permanently with a disc of sheet tin. The whole is painted black as a protection from the water.

They are made up in sets of from 6 to 12 of each particular depth of immersion required; of every length, advancing by a half-foot, from 1 foot (depth of immersion) to the extreme depth of immersion required.

When in use, they are laid out on long planks with raised edges, (forming a sort of "plank-tray") to save risk of bending by their own weight, as they are of course somewhat fragile.

Site, &c.—The site chosen for the section at which the Discharge is to be measured should be a very long straight reach, in which the cross-section, and physical condition of the banks and bed are pretty uniform for a long distance, as far as possible from any disturbing conditions, such as Falls, Outlets, Inlets, Piers or other obstacles in the stream, &c.

Run, Pendants, &c.—The essential part of the observation consists simply in timing the passage of a "Rod" (reaching from the surface

* They are made by a common native tinsmith in the bazar, at a cost of about two and a half annas per lineal foot when made in large numbers.

nearly to the bed) over a known distance as accurately as possible. These Rods should be run at as *many different points* of the cross-section as time and convenience admit; the more numerous these are, the greater accuracy is attained in the Result.

This known distance (technically called the "Run") is defined by stretching two Ropes across the stream at right angles to the thread of the current at the required distance apart. A distance of 50 feet will probably be found the most convenient* for this purpose.

Pieces of white Rope (technically termed "Pendants") should be attached to these Ropes, and allowed to hang from them nearly down to the water-surface, to define the positions under each Rope close to which the Rods are to be passed.

Cross-sections.—Several cross-sections should be taken by sounding right across the stream: there should be at least three of these; viz., one at each of the Ropes which define the "Run," and one half way between; any others should be in pairs at equal distances (of half the length of the "Run") above the upper Rope, and below the lower Rope. The soundings should be taken in each cross-section *opposite each Pendant* on the upper and lower Ropes, so that there will be a row of soundings in a vertical plane parallel to the stream through each Pendant. The average of the depths in the row of soundings corresponding to each Pendant, is to be considered the proper *value of the depth* at that Pendant, and is denoted by h_x in what follows. The (submerged) length of the Rod passed at each Pendant should be as nearly as possible of this length.

5. *Use of the Rods.*—A set of about six Rods of every length required for use should be collected on a "plank-tray" in a boat stationed about 100 feet above the upper rope. The Rods should be delivered vertically into the water from the stern of the boat, allowed to slip rapidly through the hand, and checked by the hand just before touching the bottom, and then let loose. If this is skilfully done, the Rod should leave the hand in a nearly vertical position, and acquire a state of relative equilibrium with the current long before reaching the upper Rope. The Rods should be invariably the *longest that will run freely* along each line. After the Rods have passed under the lower

* This was the standard distance used in the Experiments at Roorkee after much experience: the reasons for adopting this length are given in Art. 15 of "Hydraulic Experiments at Roorkee in 1874-75."

Rope, they should be caught and collected by help of a second Boat stationed a little way below the lower Rope.

Timing.—The essential part of this observation (timing) is in noting the instants of the Rods passing under each Rope in succession. A considerable error of "personal equation" may be introduced at this step, if not so performed as to avoid this source of error. The principle to be attended to is that the *similar observations* (of whatever kind) *at the two Ropes* should be invariably done *by the same person.* In taking the *difference* of the times of transit, all effect of personal equation should be eliminated.

Ex. 1. In using a stop-watch, the Assistant Engineer should stand at the upper Rope, and start the watch himself at the instant of transit, and then himself go down to the lower Rope, and there stop the watch at the instant of transit; being himself in this case the sole observer.

Ex. 2. In using a chronometer, one Assistant would stand at the upper Rope, and shout at the instant of transit, and then himself go down to the lower Rope and shout at the instant of transit. The other Assistant would sit with the chronometer *midway between* the ropes, and himself record the instants at which he heard the two calls.

To eliminate mere accidental observation-errors, the velocity-measurement *at each of the selected points* should be repeated at least *three times:* the mean of the three velocities may be considered the "mean-velocity" past the vertical at that point freed from mere observation-error. It will be found that the three velocities so obtained generally differ by a considerable amount: this is to be attributed in great part to *real variations in the motion of current,* and not necessarily to observation-errors.

Perhaps the most convenient way of effecting this is to start two or three Rods *as rapidly as possible one after another* from the upper Boat, so as to arrive in close succession one after the other at the upper Rope; their transits being there recorded, the observer would have to move down to the lower Rope in time to observe the earliest.

Out of a set of three started nearly together as above described, one or more will probably diverge considerably from the intended line; such cases should be simply rejected, no record being made in the Field Book: one or more will in general pass pretty close to the intended Pendant at both Ropes; the observation of these latter Rods only should be recorded. It will be found that much time may be saved by* working in this manner.

* This procedure was adopted in the Hydraulic Experiments at Roorkee after much experience.

Reduction of the velocities.—

t_1, t_2 the chronometer times of transits at upper and lower Ropes.

$\therefore t_2 - t_1$ = interval of passage through the Run, which may be conveniently expressed in seconds, or half-seconds.

s = length of "Run", measured say in *feet*.

Then $\frac{s}{t_2 - t_1} = \left\{ \begin{array}{l} \text{velocity through the "Run" in same units of time} \\ \text{and length as used in } (t_2 - t_1) \text{ and } s. \end{array} \right.$

The velocity is usually required *in feet per second*. Much labour of reduction may be avoided by observing that if t_1, t_2 be expressed in half-seconds, (as would naturally be the case with a half-seconds' chronometer,) and s = 50 feet, then the velocity $= \frac{50}{t_2 - t_1}$ (feet per half-second) $= \frac{100}{t_2 - t_1}$ *feet per second, i. e.*, the velocity *in feet per second* = 100 × the reciprocal of the time of passage (taken in half-seconds); this may be taken (by inspection) from a Table of Reciprocals. This reduction is easily done in the field.

6. *Calculation of Discharge.*—

Let x = distance of any velocity-measurement from one bank, or from mid-channel, *in feet*.

h_x = average depth along this line *in feet*.

v_x = observed velocity of Rod along this line *in feet per second*.

= mean velocity through depth h_x in this line (by hypothesis).

b', b'' distance of line of next velocity-measurement to right and left of above particular one (v_x), *in feet*.

Then $h_x v_x$ = (Superficial) Discharge through full depth (h_x) in line of v_x, *in sq. ft. per second*.

$h_x v_x \cdot \frac{b' + b''}{2}$ = (Cubic) Discharge through segment of breadth $\frac{1}{2}(b' + b'')$ (in the middle line of which v_x is measured), approximately,—provided the depth through this portion does not differ much from h_x.

The products of type $h_x v_x \cdot \frac{b' + b''}{2}$ are to be formed separately for every segment of *different breadth* $\frac{1}{2}(b' + b'')$ or *different depth* (h_x); the sum of all such products is obviously the,—

$$\text{Total Discharge} = \Sigma \left(h_x \, v_x \cdot \frac{b' + b''}{2} \right) \textit{ cubic feet per second.}$$

The more numerous the points of velocity-measurement, the more accurate will be the Result. To secure the *best* Result, these points must, however, be suitably distributed. As a general Rule, there should be one at every considerable change of depth or figure in the cross-section, and they should be closer together when the velocity changes most rapidly, *i. e.*, near the margins.

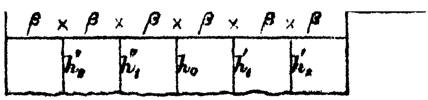
For the purpose of application of good approximation-formulæ in calculating the above sum, however, it is advisable that the cross-section be either

1°,—divided into equal sub-divisions by the lines of velocity-measurement, in which case every $b' = b''$, ($= \beta$ suppose).

2°,—divided into a large central segment, and one or more smaller marginal segments on either side of it : each of which should be separately divided into equal sub-divisions by the lines of velocity-measurement.

The following modes of sub-division are proposed as suitable for case of Canals which are usually of rectangular or trapezoidal section, with a bed tolerably level through great part of its width. The number of distinct points of velocity-measurement proposed being only 5, 7, or 9 in the three cases described, should not unduly tax the practical Engineer.

Rectangular Section.—In a rectangular section of tolerably uniform depth right across, by far the best sub-division to employ is into *six* equal parts,—as this admits of the application of the *best* approximation-formula (known as Weddle's Rule) : this requires the observation of velocities at *five* points in the cross-section; the velocities at the margins may be assumed zero.



Let β = breadth of a division *in feet* = $\frac{1}{6}$ full breadth.

h_0 = central depth *in feet*.

h_1'', h_2'' ; h_1', h_2' the depths at distance of one, and two divisions to left and right of centre respectively, *in feet*.

v_2'', v_1'', v_0, v_1', v_2' the "mean velocities" through depths h_2'', h_1'', h_0, h_1', h_2', respectively *in feet per second*.

Then "Weddle's Rule" gives—

Total Discharge $= \frac{3}{10}\beta\left\{h_1''v_1'' + h_0v_0 + h_1'v_1' + 5(h_2''v_2'' + h_0v_0 + h_2'v_2')\right\}$.

By Simson's Rule this would be—

Total Discharge $= \frac{1}{3}\beta\left\{4(h_2''v_2'' + h_0v_0 + h_2'v_2') + 2(h_1''v_1'' + h_1'v_1')\right\}$,

or, if the rectangular cross-section be of nearly uniform depth (h) right across, (so that all the quantities denoted by h_x are sensibly equal,) these take the simpler forms.

(Weddle's Rule), Discharge $= \frac{3}{10}\beta h\left\{v_1'' + v_0 + v_1' + 5(v_2'' + v + v_2')\right\}$.

(Simson's Rule), Discharge $= \frac{1}{3}\beta h\left\{4(v_2'' + v_0 + v_2') + 2(v_1'' + v_1')\right\}$.

Trapezoidal Section.—In a trapezoidal section with tolerably level bed and tolerably even side slopes, perhaps the best way is to divide the cross-section into a "central segment," embracing the whole space *between* the side-slopes, and two "marginal segments" including only the spaces *over* the side-slopes.

Velocity-measurements should be made over the foot of each side-slope, and also *half-way between* the foot of the slopes and the margins. The central segment may then be divided into *four* or *six* equal parts by the pendants. This will involve of course either *seven* or *nine* distinct velocity-measurements.

Using (as before) single and double accents to right and left of the centre, respectively,

β'', β, β' = breadths of a division of left, central and right segments *in feet.*

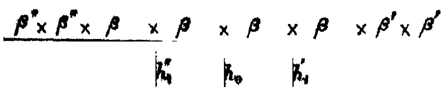
h'', h' = depths half-way up the left and right slopes *in feet.*

h_0 = central depth *in feet.*

h_1'', h_2'', h_3''; h_1', h_2', h_3' = depths (in central segment) at distances of one, two, three divisions to left and right of centre *in feet.*

$v'', v_3'', v_2'', v_1'', v_0, v_1', v_2', v_3', v'$, the "mean velocities" through the depths $h', h_3'', h_2'', h_1'', h_0, h_1', h_2', h_3', h'$ respectively, *in feet per second.*

[*N.B.*—h_3'', h_3'; v_3'', v_3' are only required when the central segment is sub-divided into six equal parts. The figure shows the notation when the central segment is divided into only *four* parts].



Then supposing the central segment to have been divided into *only* *four* equal parts, Simson's Rule is applicable to *each* of the segments, (each being sub-divided into an even number of parts); thus the velocities at the margins being assumed zero,

Discharge through left segment, $= \frac{1}{3} \beta'' \; (h_2'' \; v_2'' + 4 \; h'' \; v'')$.

Discharge through centre segment, $= \frac{1}{3} \beta \; \{h_2' \; v_2' + h_2'' \; v_2'' + 4 \; (h_1' \; v_1' + h_1'' \; v_1'') + 2 \; h_0 \; v_0\}$

Discharge through right segment, $= \frac{1}{3} \beta' \; (h_2' \; v_2' + 4 \; h' \; v')$.

Also supposing the central segment to have been divided into *six* equal parts. Weddle's Rule is applicable to the central segment, and Simson's to the marginal segments; thus,

Discharge through left segment, $= \frac{1}{3} \beta'' \; (h_3'' \; v_3'' + 4 \; h'' \; v'')$.

Discharge through centre segment,

$$= \tfrac{3}{10}\beta \{h_3''v_3'' + h_1''v_1'' + h_0v_0 + h_1'v_1' + h_3'v_3' + 5\,(h_2''v_2'' + h_0v_0 + h_2'v_2')\}$$

Discharge through right segment $= \frac{1}{3} \beta' \; (h_3' \; v_3' + 4 \; h' \; v')$.

Simson's Rule might of course have been applied to the centre segment in this case also, but Weddle's Rule gives a better approximation with no increase of labour of calculation.

[If the depths (h) be nearly equal, all the above formulæ may be simplified in appearance, by placing this symbol outside the brackets; the labour of the numerical work will also be *greatly* reduced].

Suggestions towards obtaining data for the advancement of Hydraulic Science.

7. It would add much to the utility of the Results of Discharges in large Canals obtained by the above purely experimental *direct* method, if on every occasion of such measurement, the two following data were also carefully obtained (for the same section), viz.,

1°,—Central Surface Velocity, (v_0)

2°,—Surface Slope, (S).

These two data by means of the formulæ

Mean Velocity $= \mathbf{c} \, . \, v_0$

Mean Velocity $= \mathbf{C} \sqrt{r \, S}$

would furnish two independent values of the mean velocity for comparison with that obtained by simply dividing the former experimental Result by the sectional area, viz.,

Mean velocity $= D \div A$.

These data if simultaneously obtained in considerable number at the *same* cross-section, would furnish most useful data for the advancement of Hydraulic Science.

Canal Discharges are so commonly measured at the same cross-section, that with a little expenditure of time and trouble, it ought to be quite possible gradually to accumulate a considerable quantity of these comparative data for the usual places of Discharge-measurement, without incurring any special extra expense.

To be of any real scientific use, the site chosen must be a favourable one, (*see* hints under sub-head *Site* above,) and the two elements required (v_0 and S must be measured with all possible care).

CENTRAL SURFACE VELOCITY v_0.—This should be measured not less than 30 or 40 times rapidly in succession, (this can be done in about 20 minutes,) to secure a really good "average" value freed from the effects of time-variation, with due attention to the hints above given under sub-head *Timing*. It will be of little use attempting the observation at all, unless the weather is nearly calm. The direction and force of the wind when light should be recorded.

SLOPE (S).—This observation is a very delicate one : unless done with great care, it will be of no use.

The observation consists simply in finding the difference of level of two points of the water-surface at the margin *at the same instant*, at equal distances above and below the section of experiment.

These two points should be on same bank, and at spots where the cross-section and longitudinal section of the channel are both geometrically and physically similar, and which are also symmetrical, both geometrically and physically, with respect to the section of experiment. These points should be as close to the bank as possible, so as to be in slack water, the slower the better ; and should be points of *nearly equal* velocity*, if the water be in motion.

As a preliminary, two permanent bench-marks should be established on the same bank as close as possible to the places where the water-level is to be hereafter observed, and their difference of level found with the utmost possible accuracy.

The actual observation will then consist simply in connecting the level of the water-surface at the two chosen points with the bench-marks *at the same time*. This must be done on a calm day only, by two observers working *simultaneously* by signal.

The exact mode of connecting the water-surface with the bench-marks must depend on the nature of the banks. The best mode is that which interferes least with the normal motion of the water : the level of the *maximum and minimum oscillations* of the water must be invariably recorded.

[With the usual sloping earthen banks, the best plan would probably be to drive a stout peg into the bank close to the water's edge, *where the water is very shallow*, till its top is nearly flush with the soil, (and the water quietly flowing over it as before). The top of this peg may now be considered a *temporary* bench-mark, and may be connected with the permanent bench-mark in the ordinary way. Similar pegs (temporary bench-marks) would be used at both ends. The actual observation would then be reduced to finding the height of the water-surface above the tops of these pegs. This is very conveniently and accurately done by inserting a very thin brass scale (divided to tenths and hundredths of feet) into the water, until it rests on the top of the peg, and then reading the height of the maximum and minimum oscillations of the water-surface off the scale. Such a scale will be found to ruffle the water very slightly if not thicker than $\frac{1}{32}$-inch and held parallel to the current, the peg being supposed to be close to the margin where the current is slack. This part of the observation must be done on a calm day, and *simultaneously* at the two ends by the two observers. The above process gives probably as much accuracy as is possible].

* If there be any considerable difference of velocity, this alone may cause a sensible difference of level, independent of the real slope of the water-surface.

The actual result of this observation will be the fall of the water-surface between the two distant points: this fall divided by the distance in question will be really the "average slope" throughout that distance, whereas the quantity S of the formula, should in strictness be the surface slope at the section of experiment itself. It is therefore very desirable to make the distance between the two extreme points the least possible* consistent with securing the requisite accuracy of estimating the whole fall.

[About half a foot of fall should be enough to admit of the requisite accuracy of estimating the fall: the two extreme points should then be so spaced as to ensure a total fall of about half a foot].

If these data (v_0 and S) be obtained *along with* the Discharge-measurement by the Rods for a *great range of depth*, the algebraic expressions for **c, C** proposed by Bazin—given in formulæ (3), (2) above—could be verified or tested for each Section of Experiment, the special values of the constants α, β being of course determined anew for each Section.

It is essential to the propriety of the comparison, that the three observations (for V, v_0, S) be all taken *as nearly as possible together*, so as to be under same conditions of depth, and state of Canal: to be of the greatest use, they should be taken *only when the Canal is "in train,"* (*i. e.*, when neither rising or falling,) as those taken in different "states" (of rising or falling) will probably not be fairly comparable. To be used for verifying formulæ, it is also essential that they extend over a great range of depth, (not less than half the entire range).

The writer would be glad to receive statements of the comparative data above mentioned, (V, v_0, S) for the purpose of verification of the algebraic expressions for the coefficients proposed by M. Bazin, Kutter, and others, if carefully compiled in Form on next page, with due attention to all the precautions described above, and extending through a considerable range of depth. A cross-section should accompany.

* In many standard Text-books a two-mile length is laid down for this purpose: the author considers that a good deal of the apparent discordance of the results of the three formulæ is due to a too rigid adoption of this great length, within which there may possibly be several changes of slope.

Data for verification of formulæ for Mean Velocity.

Place.

Date.	Depth at Gauge in feet.	Area of section in sq. ft. A.	Wetted border in feet. B.	Hydraulic mean depth in feet. r.	Results with Rods. Wind. Direction.	Results with Rods. Wind. Velocity or Force	Results with Rods. Discharge in c. ft. per sec. D.	Results with Rods. Mean Velocity $V = \frac{D}{A}$	Results with Central Surface Velocity. Wind. Direction.	Results with Central Surface Velocity. Wind. Velocity or Force	Results with Central Surface Velocity. Central surface velocity v_0.	Results with Central Surface Velocity. Coefficient $c = \frac{V}{v_0}$	Results with Slope. Slope S.	Results with Slope. Product $\sqrt{rS}$	Results with Slope. Coefficient $c = \frac{V}{\sqrt{rS}}$	Remarks.
											To be the mean of at least 30 observations.		The surface level must be observed in calm air only by two observers at same instant.			The observations for the three Results (D, v_0, S) must be made only while the canal is in train, as near together as possible. 2. The most convenient way of entering the direction of the wind is to reckon the line of the canal as the meridian (N. S.) line. If there be no anemometer available, the force of the wind may be estimated as "light", "strong", "high", &c. 3. A cross section to accompany.

No. CCXXXVI.

MORE LEAVES FROM A SUPERINTENDING ENGINEER'S NOTE BOOK.

[*Vide* Plate XXXIV.]

BY COL. J. G. MEDLEY, R.E., *(late) Supdg. Engineer, 1st Circle, Punjab.*

Flood Discharge of Nallahs.—It is often said with great truth, that the Engineer learns more by one failure than by a hundred successes. And in that view, it may be useful to record for the benefit of others, the recent failure of two bridges near Rawal Pindi, and to see what lesson can be learned from them.

The Leh Nallah runs close to the town of Rawal Pindi, rising in the neighbouring hills, and draining an area of about 70 square miles. In its course near the town it is a deep sandy nallah, carrying a mere thread of water generally, but liable to sudden and violent floods.

It is here spanned by three bridges, the first of which in point of date was built 15 years ago, and carries the Murree Road over the nallah. This consists of three spans, timber trusses on masonry piers, giving 150 lineal feet of waterway, with a depth of 20 feet from the nallah bed to the bottom of the girders.

The second bridge built half a mile higher up some years later, had three masonry arches of 60 feet span and 12 feet rise, with a depth of 20 feet from the spring of the arches to the nallah bed.

The third bridge built still later and still higher up, had also three openings of 60 feet, timber trussed girders, and like the former 20 feet above the nallah.

Although the waterway of the first had never been found insufficient for many years, the designer of the second bridge evidently thought that it was so, and the designer of No. 3 followed his example so far as the lineal waterway was concerned.

On the evening of the 25th July last, a heavy fall (2·5 inches) of rain occurred at Rawal Pindi, followed after an interval of 6 hours by a fall of 8·5 inches in 10 hours, of which 6 inches fell in 6 hours.

The water rose in the nallah to a depth of 26 feet at the upper bridge, and to within 18 inches of the roadway on the top of the girder, and bringing down a quantity of timber with it, which was stopped by the trusses; carried away the whole superstructure of the bridge. The flood then passed through the arches of the second bridge at a height of 8 feet above the arch rise, and then carried away the girders of the lower bridge also, rising to a height of 3 feet above the roadway, and inundating the road and surrounding country for a considerable distance. So sudden and violent was the flood, that many people had to escape up the trees, from which they were afterwards picked off (like apples) by means of elephants. This occurred at 7 A.M.; four hours later the stream had fallen to its usual low level.

On examining the scene of the disaster two days later, and taking the necessary levels, it was at first difficult to account for the extraordinary height of the flood marks. The fall of the bed was 6 feet per mile, and the velocity resulting from the employment of the usual formulæ gave 13 feet per second, and a discharge equivalent to a fall of 2 inches per hour over the whole drainage area. This amount, over an area of 70 square miles, was hardly creditable, and as it appeared on investigation that the sandy bed of the nallah was very little eroded, it seemed clear that no such velocity as that calculated could have been obtained.

Careful comparison of the flood levels at different points showed that the water had been dammed back or ponded up in the nallah itself, which was of insufficient section to carry so unusual a flood, and hence, while the depth of the water had been abnormally increased, the velocity had been considerably diminished.

Making allowance for this, however, the calculated velocity as deduced from the slope of the flood line was certainly very much higher than could reasonably have been expected, judging from the state of the bed, and the only conclusion that could be come to was, that the formulæ in question are not reliable.

On the facts above noted, I make the following general remarks:—

The ordinary methods of determining the flood discharge of any stream are as is well known.

1. From cross sections of the channel taken up to the line of highest flood, the velocity being calculated by formulæ derived from levels taken of the slope of the bed or of the surface of the flowing water.
2. From calculations of the rain fall over the catchment basin, or area drained by the stream.

With regard to the first method, the determination of the cross section is an easy matter enough, so long as we have reliable flood marks. These, however, are by no means easily obtained, especially if any long time has elapsed since the last high flood. It is most difficult to get exact and reliable information from natives on such a point, and it is only by obtaining corroborative evidence of their statements, in various indirect ways, that any confidence can be felt in them.

It is also to be borne in mind that information so obtained, refers only to the past, and is often an insufficient guide to the future. There is scarcely ever a flood that sweeps away a bridge, of which you are not assured that it is the highest flood that was ever known to have occurred at that particular place.

One conclusion to be drawn from this is, that on the occurrence of any extraordinarily high flood, permanent marks recording the height and date of such flood at various points, should be fixed by the Engineers concerned, and this ought to be a standing rule of the Department.

But, difficult as the determination of the correct flood line often is, the calculation of the velocity during a flood is much more so. The two formulæ commonly used, and which will be found given in the Roorkee Treatise, are,

(1), Dubuat's—

$$v = 92 \sqrt{2ds}$$

Where v = mean velocity,

d = hydraulic mean depth,

s = slope of the channel in feet per mile.

(2), Neville's—

$$v = 90\sqrt{\frac{d}{s}}$$

Where v and d are as before—

s = slope of the channel in unity.

Now, from whatever experiments those formulæ have been derived, there can be no doubt that, in the case of most Indian water-courses, they are quite unreliable. They may possibly be correct enough for canals or water-courses of regular section, and running uniformly in straight reaches. But for large streams of irregular section, liable to great fluctuations, and to hill torrents with great declivities of bed, and subject to sudden and violent floods, these formulæ give velocities which are far too high. A little experience will show that in many cases which occur in practice, the above formulæ will give calculated velocities of 12 feet or more per second, while actual observation will show that even the surface velocity does not exceed 6 feet. One proof of this will be found, as in the present case, in the small erosion of a nallah with a sandy bed, after a flood which, if the calculated velocity were reliable, would tear it up to a depth of several feet. Moreover, a very little observation of a stream in flood will show that the highest observed velocity is confined to a very small portion of the breadth of the channel, that the velocity of the rest is much less, and that a portion of it is even backwater.

Another fact is also to be borne in mind of which no formulæ can take account, viz., that in the case of sudden and severe floods, the water flowing down is headed up very much at the bends, and also against the banks of the stream itself, and so much so, that while the depth of the stream is greatly increased, the velocity is actually diminished.

The American formulæ given in page 90 of the Roorkee Treatise, Vol. II., will be found to give results much nearer the truth in the cases above-mentioned, but we very much want some reliable formulæ for the peculiar case of Indian rivers and streams, with a view of determining the average velocity of the cross section in flood, and a great service will be done by any one who would carry out a series of accurate observations on rivers, nallahs, or mountain torrents in flood.

On the whole, it may, I think, be laid down that in the case of large nallahs, subject to sudden floods, with declivities of channel of 5 or 6 feet per mile, the average velocity of the cross section during such floods will not exceed 5 or 6 feet per second, even with a depth of 20 feet of water passing down, and that this is proved by the slight action that will be found on the bed and sides of the channel.

The determination of the flood discharge by an assumed rainfall over the drainage basin, of course presupposes that we have a map sufficiently accurate to enable us to measure the area of the basin. This being done, it is believed, that the Dickens' formula quoted at page 101 of the Roorkee Treatise, Vol. II., may generally be accepted as a safe guide certainly in Upper India.

$$D = 825\ A^{\frac{3}{4}}$$

D being the discharge in cubic feet per second, and A the area of the drainage basin in square miles.

It proceeds on the assumption that the greatest rainfall over a given area varies inversely with the extent of such area, so that while a very small drainage basin may be expected to discharge a flood like 2 inches in an hour, a large basin would not discharge more than $\frac{1}{4}$ of an inch in the same time; or to speak more correctly, that very heavy rain storms are confined to very small areas.

In estimating the proportion of flood discharge to rainfall, it is often laid down that a certain, perhaps a considerable, proportion will be absorbed by the ground, such proportion depending on the nature of the soil. Though this may be theoretically true, it will not do for the Engineer to make any allowance for it, for the heaviest storms usually occur, in India at least, when the ground is already thoroughly saturated, as in the present case, so that provision should always be made for the full quantity known or assumed to fall over the whole basin in a given time.

In estimating the velocity with which such floods are passed down the drainage channel, we have of course the same difficulty to contend with as has been described already, and unless we find considerable erosion of the bed, it will not be safe to assume a greater average velocity than 5 or 6 feet per second.

Making this assumption, and estimating the greatest rain flood at 2 inches per hour over very small areas (say up to 5 square miles), 1 inch up to 15 square miles, $\frac{1}{2}$ an inch up to 50 square miles, and $\frac{1}{4}$ an inch up to 200 square miles, the Engineer in Northern India will probably be safe in designing the waterway for his bridges. Or he may, if he prefers, work according to Dickens' formula.

In designing timber trussed bridges, the bottom of the girder should be fixed at least 4 feet above the calculated highest flood line. If the road is in embankment on one or both approaches, as will probably be the case, long gaps may be left as an additional security against extraordinary floods, through which a considerable amount of flood water could find vent.

Design of Buildings in Upper India.—While lately inspecting some officers' quarters on the Frontier, my attention was drawn to the fact that though these buildings were erected many years ago, and were no doubt very dark and badly ventilated, with low walls, small doors, and small low verandah arches, they were yet admitted to be very much cooler than two new blocks lately constructed, with lofty rooms, high wide doors, and verandah arches ; indeed the upper stories of the latter were said to be almost uninhabitable in the hot weather. The same remark appears to be everywhere made in regard to the old (or Napier) barracks, with double verandahs, and the new double-storied barracks.

From these, and other instances, it seems to me established, that, for a climate like that of Upper India, with its great extremes of heat and cold—

1st. Lofty rooms are a mistake, because they contain too large a body of air, which when heated is with difficulty cooled, and when cold is with difficulty heated.

2nd. Large and numerous doors and windows are a mistake, for they admit cold, heat, glare and dust, to a degree quite disproportionate to their utility for ventilation, which should be separately provided for.

3rd. Broad, high verandahs, with small low arches, are the best protection to the outer walls and doors ; even when fitted with louvres, (as has been lately done in the new upper-storied barracks,) the wide, high verandahs are an insufficient protection. [The chief fault in these buildings, however, appears to be in the excessive area of doors and glazed windows or fanlights].

4th. Double verandahs are essential if we want to obtain a cool room.

Boat Bridges.—An extraordinary flood in the Cabul river, on the 31st August last, carried away the Boat Bridges at Nowshera and Daoudzaie, with some loss of superstructure; and a few notes on the best mode of securing Boat Bridges may be useful.

In ordinary cases, the boats should each be anchored by the head and stern. In the Punjab Rivers, the anchors are simply stout nets filled with large stones, which of course can never be raised. The cables are of *múnj* (a kind of coarse grass), which makes a very strong rope and lasts a whole season. Where this is not procurable, *putta* is used, a sort of reed, which does not, however, last so long as the múnj.

In addition to the head and stern anchorages, a strong chain or thick cable should connect the heads of all the boats together, and be securely fastened to each bank. And a similar rope (but which need not be of the same strength) should connect the sterns of the boats, and be similarly secured at each end. Each boat should be fastened to these head and stern ropes by a simple lashing, which can easily be cut loose, so that any boat can be slipped out of the bridge, if necessary, without trouble. The shore ends of the head and stern ropes can be secured, either to heavy stone trongahs, or to stout beams sunk 5 or 6 feet into the ground, or to masonry pillars built on purpose, or to ring-bolts fixed into rocks, (if there are any.) It will be understood that the down-stream attachments are chiefly of importance in case of a strong wind blowing *up*-stream, which often occurs.

The above mode of securing the bridge will be sufficient in ordinary rivers; where the velocity of the current is very great, and especially, if the bridge is a long one, intermediate attachments to the shore should be provided for the four or five boats in the strongest part of the stream, by separate cables securely fastened to the shore at points some distance above and below the main attachments, (lifted out of the water if necessary by an intermediate boat or buoy,) and carried across the intermediate boats. In the Attock Bridge over the Indus, there are several intermediate fastenings of this description secured to masonry pillars, built on rocks in the middle of the river. The number of such attachments must of course depend on the length of the bridge, the force of the current, and the facility with which they can be provided.

It is obvious that the boats spanning the strongest part of the stream will require stronger chains and attachments to those in slacker water and the best boats should of course be reserved for this portion of the bridge.

In a very strong river, especially if liable to sudden floods, it will be advisable to dispense with the head and stern anchorages for each boat, if the number of intermediate attachments is sufficient; as of course, if from carelessness, the former are not slacked off in time, the boats will be submerged.

In a bridge of moderate length, thus fastened, without any anchors, by the chain cable running across the bows of the boats and secured to each shore, the curve or versine of the chain should be $\frac{1}{8}$th of the span. This is done in the new bridge over the Ravi at Lahore, the chain being one inch diameter, and secured to a stout beam sunk in the ground behind a solid block of concrete. Small iron clips are provided in the bows in which the chain rests, and from which it can be easily detached when required. Similar clips are provided at the stern for the cross chain on the down-stream side. As an additional protection, every third boat is anchored on the down-stream side.

The standard Boats and Superstructure for the Punjab Rivers, as designed by Colonel A. Taylor, C.B., and approved by Government, will be found described in the Roorkee Treatise, Vol. II., page 114.

The boats are the same at the head and stern, and when in proper trim, the fore and aft keels are some inches clear of the water, which thus passes smoothly under the boat. But unless care is taken to keep the longitudinal iron ties properly screwed up from time to time, the bows and sterns are very apt to droop.

The trussed beams are of 30 feet clear span in the bays, and have been designed—

1st. So that the wood and iron should as nearly as possible, be subject to the same strain.

2nd. So that the wood may float the iron, in case of the beam falling into the water. As the trussed beams rest on the gunwales of the boats, and not on saddles over the keels, (which would much increase the length of the beam,) stiffening beams are necessary to distribute the weight properly. These pass over the boat outside the outer trussed beams and are firmly lashed to them by means of a stiffening plank passing below and across the platform.

In case of a great storm or flood threatening to break the bridge, the superstructure should be dismantled, and placed in the boats, as rapidly as possible, not carried to the shore, which would occupy longer time. If logs of timber are carried down, threatening to damage the bridge, as many boats as may be necessary can then be cast loose, and allowed to drift down the river.

The boatmen should occasionally be exercised both by day and night.

1. In dismantling the superstructure and placing it in the boats.
2. In slacking off the head and stern cables of each boat.
3. In casting them off after attaching buoys.
4. In cutting loose the boats from the head and stern ropes, and letting them float down-stream.

Sandy Roads.—I have lately gone over the road across the sandy Thal between Dera Ismail Khán and Jhung, which for 65 miles runs over heavy sand, the surrounding country being a dreary waste of sand hills thinly covered with jungle. Over this road the traveller is carried by the mail cart at a rate of 8 miles an hour (including stoppages). The greater portion of this road is laid with long grass, brought from the *kachí* or valley of the Indus or Jhelum, for a distance in some cases of 20 miles The grass was laid down 2½ years ago, and only now requires renewal, but the wheeled traffic over it is almost entirely confined to the mail carts. The width first laid was 12 feet, the grass now being laid is only 8 feet; pegs are placed 15 feet apart in the length of the road, and the space between two pegs requires five maunds of grass, or a camel load; the grass is covered with 6 inches of clay if procurable, if not, with sand. The average cost is stated to be Rs. 200 per mile. Over the sandy bed of the Chenab, on the approaches to the boat bridge, the grass is first made up into fascines of 6 inch diameter. This is of course an additional expense, and I doubt whether it is an improvement.

About 17 of the intermediate miles are laid with brick metalling 9 feet wide, 10 inches thick at the centre, and 6 inches at the sides, the cost of which is computed at Rs. 1,500 per mile.

River defensive works.—Having lately had an opportunity of seeing the works executed during the past year at Dera Ismail Khán, to protect the station from being carried away by the river Indus, I think a brief account of these may be interesting. The true bed of the river—the *kachí*, as it is termed, is here about 12 miles broad, the whole width being under water in the rainy season. In the cold weather, at present, and for some years past, the river runs in three channels; the central one carrying the main stream, and the right channel running close to the west high bank, on which, the Cantonment of Dera Ismail Khán is built. The action of the stream against this west bank has been more or less severe for many years past, the old native town was carried away some 35 years ago, and the new town which was built four miles inland, being now threatened with the same fate. Fifteen years ago the Cantonment was threatened in like manner, but its fate was averted by the works then constructed by Mr. Garbett, C.E., and it is only within the last two or three years that the danger has again become imminent, the force and velocity of the stream in the west channel having cut away the bank very rapidly. The works constructed last cold weather consisted—

1st. Of a barrier across the exit of the west channel from the main river some four miles above the station.

2nd. Of a series of short spurs to defend the bank immediately attacked.

The barrier was nearly half a mile long, and was begun from both ends at once, to prevent the further end being turned by the stream being forced against it. The work consisted of a line of whole trees lashed together, weighted with stones in nets, and sunk to the bottom of the river, above which other trees were piled, until the surface of the water was reached. As the two ends of the barrier approached each other, the scour caused by the current rushing through the interval was so great, that the water was found to be 40 feet deep, and the barrier was never entirely closed. It was, however, maintained until June, when it was topped by the rising flood, but when the river had fallen again, it was found to have done good service. The flow of water down the western channel had been so lessened, that whereas there had been a depth of 30 feet opposite the station in October 1875, there were only 5 to 8 feet in October 1876.

The spurs were constructed in the same manner as the barrier, piles being added in rear of the mass of trees, when the rush of water threatened to carry away the whole bodily. Their effect has certainly been very great; an immense quantity of silt having accumulated, both in front and rear of them, so that at one place a considerable foreshore had been reclaimed, which is now being planted with willow, tamarisk, and other quick growing trees.

As an adjunct to the spurs, a considerable number of "Brownlow Weeds" had also been used, the weed consisting—

1st. Of a cask (or a couple of casks lashed together) floating on the surface, and anchored by along cable to a *trongah*, or net of stones.

2nd. Of branches of trees tied at intervals on the length of the cable;

these of course float with the current, and like natural weeds, check the velocity of the stream, and cause a considerable deposit of silt. When used in sufficient numbers, they appear to answer well, and to create a considerable shoal.

Whether the above works will prove permanently effective, is of course very questionable; they have at any rate warded off the immediate danger.

Such solid tree spurs as I have described appear to answer well, the objection to them is the necessary destruction of trees in a very treeless country. Floating tree spurs, consisting of a line of trees tied to a cable securely anchored, also answer well, especially as breakwaters to protect a bank or solid spur behind.

Fascines may also be used for solid spurs, and can often be procured when trees are not available; they may be laid in layers (weighted with stones if necessary) alternately headers and stretchers, the spur having a good broad base.

The trouble with all spurs is to protect their ends or noses, where the action of the stream is very strong. A mass of floating trees with the butts well secured to the spur, or even a mass of long fascines laid endways in the water, (like a bunch of radishes,) will greatly break the force of the current.

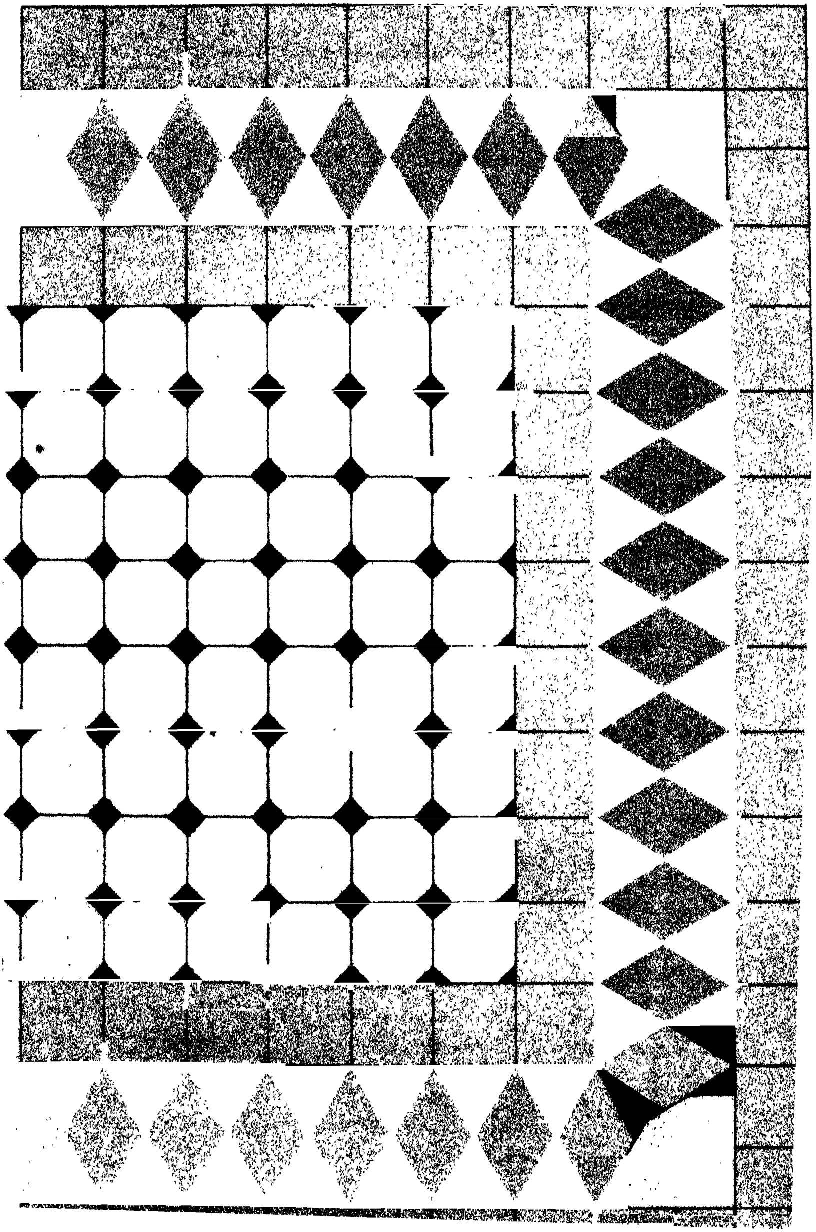
As some readers may be interested in the fate of the Sand Spurs described in my previous "Notes" some time ago, I may mention that they have now stood through three rainy seasons, and have entirely answered their purpose. I only recommend them, however, for *intermittent* streams, as they cannot, from the nature of the material, resist the continual action of water.

Coloured Flooring Tiles.—Annexed is a copy of a report by Captain Lovett, Executive Engineer, Hazára, on experiments made in the manufacture of coloured flooring tiles at Abbottabad.

We have now succeeded in making and burning excellent tiles of red, black and buff or cream colour in several shapes, and uniform in colour, size and thickness, and I have now laid down in my own verandah a strip of tesselated flooring 120 feet square after the pattern annexed, (*Plate* XXXIV.,) which looks very well, and is much admired. The tiles were all brought from Abbottabad, and the flooring (composed of 795 separate pieces three-fourth inch thick) was very well and evenly laid by ordinary

SPECIMEN OF TESSELATED FLOORING

In Verandah of Colonel Medley's house at Rawalpindi.
Tiles manufactured at Abbottabad.



mistrís, at a total cost of Rs. 35 per 100 square feet. This rate in future cases we shall be able to reduce to Rs. 30, as the cost of carriage from Abbottabad (64 miles) for so small a number was disproportionately high, and the cost of laying as a first experiment was also extravagant.

The cost per 100 square feet will in future be—

	RS.	A.	P.
Cost of tiles, ...	*17	8	0
Carriage (64 miles), ...	3	0	0
Cost of laying, ...	8	8	0
Contingencies, ...	1	0	0
Total, ...	30	0	0

The red and buff† tiles were made of different clays, and the difficulties of unequal shrinkage were got over by mixing a small quantity of pounded pottery or broken glass with the clays before burning. The uniformity of colour was obtained by burning in a muffled kiln (shown in Captain Lovett's report), so as to prevent the smoke and flame coming in contact with the tiles. The black tiles were burnt in closed vessels with *meng* or goats' dung in them. Several shades of red were obtained by mixing small quantities of red sandstone with the clay.

The cost of carriage, will, of course prevent the use of these tiles at any station far distant from Abbottabad, but doubtless clays of these kinds exist at many other stations besides Abbottabad, and perhaps if this account of our success here were made known, it would draw attention to the subject, and these very useful and ornamental floorings, which are so admirably adapted to this country, might be more generally employed.

If these tiles could be made at any place on the line of railway, such as Allahabad for instance, they ought to command a large sale for the floors of public rooms, churches, halls, and even, instead of carpets in the hot weather, for private houses.

I hope to obtain several orders for similar floors.

Report by CAPTAIN B. LOVETT, R.E., C.S.I., *Exec. Engineer, Hazára Division, on Experiments in Manufacture of Flooring Tiles at Abbottabad.*

I have delayed till now making any report on the manufacture of flooring tiles,

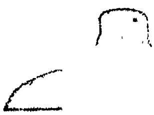
* This would also be reduced if large numbers were made.

† The buff tiles are made from a white clay like Fuller's earth.

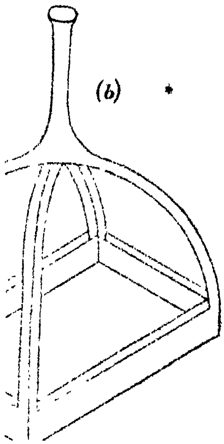
because until certain experiments had been made and certain experience gained, there was hardly anything to write about.

In June 1875, I brought to your notice some specimens of hexagonal tiles that following Major Waterfield's example, I had moulded and burnt at the village of Shekh Banda, about one-and-a-half miles from Abbottabad.

These tiles were moulded in this manner. First the clay, hand-tempered, was spread out flat by the *kumár* on a plank by a *kandára*, or flat disc with a handle. This little instrument is made of wood of the pattern shown in the annexed figure (*a*). When the proper thickness has been attained, varying from one-third to half or five-eighth, of an inch, an iron stamper or die (*b*), is used to cut out patterns, square, hexagonal



(*a*)



(*b*)

or lozenge shapes. These stampers should have a slight bevel, so that the upper side of the flattened out clay, which is the underside of the tile, may fit close, and an interstice for the cement, in which the tiles are to be laid, may be left.

The tiles thus made were burnt in a small clamp about 10′ × 8′, and turned out pretty fair. The black tiles were coloured by burning them in a closed vessel of earthenware, in which goats' droppings (*meng*) were placed.

I had some flooring carefully executed with the above tiles under personal superintendence, which has answered satisfactorily.

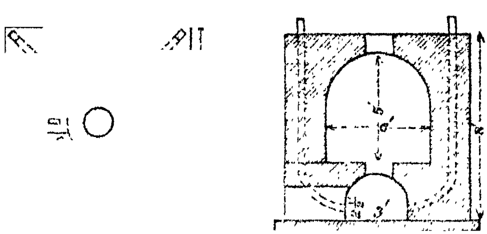
You approved of the specimens I submitted for your inspection, and desired further experiments to be made, directing my attention particularly to the information given on coloured flooring tiles in the Roorkee Treatise.

Before I had time to prosecute further enquiries the rains commenced, and in July my transfer temporarily to the Kohát Division took place, so that I was not able to commence any experiments until I was re-posted to this Division.

I then had a kiln built close to the bazár, and to the residence of my Draftsman, Gholám Haidar, who has throughout chiefly conducted the experiments. By this means I was able at all times to see what progress was going on whenever I happened to be in Abbottabad.

My kiln (plan and section given in margin) is very simple, and cost only Rs. 10. It is provided with four chimneys at the corners for the escape of the smoke, and under the lower dome, on which the articles to be fired are placed, is the furnace. This lower dome has a circular aperture 18 inches or 24 inches diameter at top, and through this the flame flares up, but does not actually come in contact with the ware.

Plan. *Section.*



In firing goods, we find six hours with a gradually increasing fire suffice thoroughly to dry and prepare the things for fiercer heat lasting 8 or 10 hours, and the average quantity of fuel used has been 14 maunds.

My instructions were to obtain, if possible, tiles of three colours—black, red and buff or grey. I therefore directed experiments should be made with various mixtures, and have had tolerable success. The earths used have all been procured within short distances of this place. Therefore, should the manufacture of these tiles be developed, and not only tiles, but *terra-cotta* ware generally, it will tend much to economy, having all the necessary earths close at hand.

Unfortunately the rains during, and since the spring, have been so persistent, that our operations have been interrupted with the most vexatious frequency, otherwise I should have reported on our progress long before now.

I submitted specimens of hexagonal tiles 5½ inches diameter last May for your approval. These were composed of clay 6 parts and 1 part powdered pottery.

You directed square tiles 8 inches square should be made to lessen expense in laying as flooring.

Our efforts have accordingly been directed to the manufacture; I regret that, as regards black tiles of that size, our operations have been failures. On both occasions when we fired these tiles, the black tiles burnt in closed and heated vessels have turned out black certainly, but all broken.

Our last turn out (August 29th) contained a few experimental square black tiles 6 inches side; these have turned out successfully, and did not break in the burning.

I therefore think the size 8″ × 8″ is too large. Probably unequal contraction and expansion has something to do with it, though why tiles bedded in goats' dung and burnt in a closed vessel should be more subject to breakage than others burnt in the open kiln, I am not able at present to state.

The composition of the large tiles was as follows:—

Red, 12 clay 4 powdered pottery.
Dun, 16 clay 1 powdered glass.
Black, 12 clay 4 forge ashes (these broke).

Of the 8″ × 8″ tiles lately burnt (28th August), the composition was as below:—

Red, 12 clay, 5 sand, 2 powdered pottery.
Dun,
Black, (also broke).

The dun-coloured tiles were also burnt in a closed vessel, but, instead of goats' droppings, bones were used.

Whilst using the kiln, we have had various specimens of pottery burnt, glazed and unglazed, as I deemed it of importance to obtain some practical knowledge of the various clays and fluxes here obtainable, with a view to utilization in the carrying out of usual routine work. I have no doubt that in this district there is a vast reserve of materials that has never yet been properly used. There are various kinds of clays, slates, granites and limestones, besides various metallic *ores*. From the clays no doubt excellent *terra-cotta* can be made, and flooring tiles of several colours.

Encaustic tiles, which can be so suitably used for interiors, can be made well and cheaply coloured with native earths, and the only thing required is more knowledge on the subject, and where to find the ingredients than I possess at present. I am confident the manufacture only wants encouragement to succeed. I attempted to press some tiles, but have not yet perfected the apparatus. We pressed the tiles when too soft; I doubt not, however, that well pressed tiles when burnt will be denser, more hard, compact, and lasting than unpressed ones.

I forward specimens of the tiles lately turned out. The shrinkage, it will be seen, is not uniform; the least being for the mixture of clay and powdered glass, and the highest for tiles burnt in a closed vessel.

From this it appears each kind of tile must have separate dies.

The densest appears from its weight to be a tile of 12 clay, 5 sand, and 2 powdered pottery.

Financially the state of the experiments is thus—we have spent Rs. 167-11-8, the outturn has been 1 kiln, 2,390 small tiles, 180 8-inch tiles, 200 6-inch tiles, 700 Jhelum tiles, 700 coping tiles, 300 glazed pottery, 300 unglazed.

This expenditure can be also shown thus—

	RS.
Kiln-rent of shed and stock (planks), ...	20
Fuel and material, ...	50
Pay of coolies, potters, and supervision, ...	100

With the small balance in hand, I am not prepared to recommend further experiments unless a supplementary grant be accorded. This, I hope, will be the case, as I think the stage we have arrived at is just the turning point in the success or failure of the manufacture.

Gholam Haidar, Draftsman, who has displayed indefatigable industry and intelligence in conducting the operations of mixture, tempering, moulding, drying and firing at very considerable inconvenience from the unpropitiousness of the climate, thinks the sale of various articles, such as flooring tiles for private individuals and other pottery that we have on hand now, will fetch Rs. 60. This would give me Rs. 90 to go on with. I think perhaps Rs. 60 altogether the safer figure.

I should recommend then that the manufacture of the 8-inch square tiles be discontinued at present. They are difficult to stamp true, dry with less homogenity than those of less size, and we fail in burning black ones.

I suggest that 6-inch square or hexagonal ones whose side is the radius of a circle circumscribing the above square and its subsidiary forms be adopted. Also that as so much time is wasted, and money lost by inclemency of the weather, a proper drying-shed be constructed, as removal into sunshine and under shelter which the tiles have been submitted to is very injurious to their shape.

The drying-shed will cost Rs. 100. Probably Rs. 50 will suffice for our present purposes, as regards the pay of coolies, potters, fuel, &c., until we secure an organized sale for the tiles to the works in this and other Divisions, and to private parties.

I therefore solicit a supplementary grant of Rs. 150, for continuing experiments on different coloured flooring tiles, glazed and unglazed.

A box containing specimens of our flooring tiles has been forwarded to Doctor Murray Thomson at Roorkee.

A further report was submitted in November last, which, however, contains nothing of special interest. The tiles last made are six inches square and three-fourths inch thick, those first made being half inch only. Some excellent glazed tiles were also sent—blue, white and green. Also some *suráhís* made of a yellow clay which promise well.

J. G. M.

No. CCXXXVII.

USEFUL AUSTRALASIAN TIMBERS.

By H. G. McKinney, Esq., *Assist. Engineer, Northern Division, Ganges Canal.*

Among subjects of interest to the Indian Engineer, there are few regarding which so much misapprehension exists as the Australasian timbers. This remark is especially applicable to the eucalypti. In the report of a select Committee on Victorian woods, so recently as 1875, it is stated that, "although a good deal of affected knowledge is displayed as to these woods, it is difficult to distinguish them from one another with any degree of certainty, so that almost all the sawn colonial hard wood is called "blue gum," in virtue of the exceptionally good qualities of an *imported* article which no longer finds its way here, and is indeed scarcely to be procured in its original habitat." (The imported tree here referred to is the Tasmanian blue gum or eucalyptus globulus). Under these circumstances, it occurred to me lately when spending some months in the Australasian colonies, that it would be a useful pastime to collect information, both by personal observation, and from the best official and other records, regarding the woods commonly used there in construction, and also regarding those exported or likely to be exported to India and other countries.

In Victoria four-fifths of the trees belong to the genus eucalyptus, of which on the authority of Hooker, there are said to be no less than fifty five varieties in that colony and New South Wales. In both colonies the most important of these is the *red gum*. It grows to a height of from 80 to 120 feet, with a diameter of from 3 to 5 feet, and furnishes a hard, reddish-coloured wood, of specific gravity 1·12. It is remarkably durable in damp ground and in water, whether salt or fresh, and it shrinks less longitudinally than almost any other of the eucalypti. On the other hand it has a short and somewhat wavy grain, which renders it unsafe for beams or for other purposes where horizontal bearing timbers are required. Its great durability in water and in damp ground, and the resistance it affords to the attacks of the teredo, render red gum most valuable for piles for engineering works. It is also highly prized for sleepers and for the planking of bridges, wharves, &c. The available supply of red gum is enormous, as forests of it extend for hundreds of miles along the banks of the four great rivers of New South Wales, and of the auxiliary branches and creeks connected with those rivers. The red gum on the Lachlan and Darling is, it should be remarked, stunted, and of inferior quality to that on the other rivers. Expensive snagging operations have to be carried on in the Murray and Murrumbidjee, chiefly on account of the great numbers of red gum trees which are uprooted and carried into them during heavy floods. A serious drawback in regard to the supply of red gum for piles is, that there is some difficulty in procuring it in long lengths and of moderately small diameter. It has been found that in the Victorian harbours, red gum resists the attacks of the teredo for many years, and that it is a matter of doubt whether for piles in sea water it is not equal in durability to jarrah.

The *ironbark* was formerly found in abundance on the hilly and undulating districts of Victoria and New South Wales, but the available supply of it is rapidly diminishing. It attains its greatest size in the eastern parts of New South Wales, where it is sometimes found 150 feet in height. It furnishes a hard reddish coloured timber, of specific gravity 1·14, which bears a close resemblance to jarrah and red gum, is extremely durable, and is one of the stongest timbers in the world.

Stringy bark is a tree which supplies much of the second class timber in the Australian market, and much of that too which is sold as blue gum. The stringy bark of Tasmania seems to be much superior to that of New South Wales and Victoria. In the latter colonies its tendency to twist or warp, and its liability to destruction from dry rot, have procured for it the reputation of unfitness for use in construction. The readiness with which it splits has, however, induced its use on a large scale for posts and rails for fences. The stringy bark of Tasmania has been used to some extent in ship building, and piles of this timber in the wharves at Hobart Town have endured for many years, and are still in an excellent state of preservation. It seems not improbable that if properly seasoned, there would be little reason to complain of its warping. Stringy bark timber can be had in very large pieces, it is hard, straight-grained and durable, and its specific gravity is slightly less than unity. Although it is very difficult to distinguish this timber from blue gum, the difference between the trees is at once apparent. The bark of the former is rough and fibrous, resembling to a considerable degree the husk of a cocoanut, and its leaves are always similar to those of the mature blue gum but smaller in size.

Peppermint is another of the eucalypti which is found abundantly in both Australia and Tasmania. It is sometimes confounded with stringy bark, though there are decided differences, the leaves of the former being much smaller than those of the latter, and its bark being much more like that of blue gum. The peppermint grows in different localities to heights varying from 80 to 200 feet. The timber obtained from it is similar in character, but inferior to stringy bark.

At least seven different varieties of eucalyptus are known as *box*, being locally distinguished as " yellow " box, " swamp " box, &c. The different varieties of box are generally found on plains at a distance from the rivers, occupying along the courses of the minor creeks, the place which red gum takes on the rivers and larger creeks, and they grow to heights generally varying from 40 to 60 feet. The woods of the different kinds of box vary much in appearance, but their properties are in many respects similar. The specific gravity is scarcely ever less than unity, and the timber is hard and tough, but is obtainable only in short pieces. Though most suitable for such uses as naves of wheels, it is extensively used for general purposes in localities where other timbers are not readily available. Box trees of nearly every variety have the great drawback of being more or less hollow, when they come to maturity.

The trees which have been mentioned, include the best known and most valued of the eucalypti in Victoria and New South Wales. Besides these, there are some varieties which will yet attract much attention. In an official publication of the former colony, it is stated that a specimen of the eucalyptus amygdalina was found in one of the mountain ranges in a north-easterly direction from Melbourne, which proved to be 480 feet in height, and that another specimen measured 81 feet in circumference.

Of the other trees indigenous to Eastern and South-Eastern Australia, probably the most important are the red cedar and the cypress pine. The former is found chiefly in the north-eastern districts of New South

Wales and in Queensland. It grows to a height of 150 feet, and a diameter of 10 feet, and the wood in colour resembles mahogany, but its specific gravity is only 0·45. Owing to the enormous quantities of this timber which are exported from New South Wales, the supply is rapidly decreasing. It was estimated in 1871, that the export to Melbourne alone amounted to 1,00,000 superficial feet per week. Red cedar combines great lightness with durability and a fair amount of strength, and it is very easily worked.

The cypress pine seldom grows to a height of more than from 50 to 70 feet, and a diameter of 1½ feet, and the timber obtained from it has only about half the value of red cedar. It is found in great abundance on sandy ridges, and on low hills. As the cypress pine is perfectly straight, and is easily worked, it is used very extensively, and the export of it is equal to that of red cedar.

The most important trees of Western Australia are the jarrah, the tewart or tuart, and the kari, all varieties of eucalyptus. Jarrah is found in great abundance on the so-called ironstone ranges. It is a hard, close-grained, dark-red wood, bearing considerable resemblance to red gum. It has obtained a very high reputation for strength and durability, and for resistance to the attacks of the white-ant and the teredo navalis. For these reasons it constitutes one of the most important of the exports of Western Australia, and considerable quantities of it have been sent to India for sleepers. The reputation of jarrah timber was seriously injured some years ago, on account of the export of large quantities of an inferior variety found in the plains; India being intended as one of the sufferers from the transaction. It was then clearly ascertained that jarrah timber of the best quality is found only on the mountain ranges.

The tuart and the kari are not so well known as the jarrah, although they both possess some exceptionally valuable properties. The former furnishes a yellowish coloured wood, which besides being one of the strongest ever experimented on, is remarkably durable when exposed to all changes of weather. The kari tree grows to a height of 400 feet, and furnishes a reddish coloured wood of great strength, but which like tuart, possesses defects, which make its value disproportionate to its strength.

Only the two principal New Zealand trees may be briefly noticed. These are the *kauri* and the *totara.* The former is restricted to the northern part of the North Island. It attains a height of 160 feet and a diameter of 12 feet, and it is straight and symmetrical. It is extensively exported to England and elsewhere for masts, spars, &c., the quantity exported being 7½ times greater than that of all the other timbers put together.

The totara is found throughout the colony. It grows to a height of from 50 to 70 feet, and attains a diameter of from 4 to 6 feet. It is very valuable for piles of wharves, as it resists the teredo for a long period, and for general purposes it is more durable than kauri, notwithstanding the deservedly high reputation which the latter possesses.

The only Tasmanian tree which I propose to describe is the blue gum or eucalyptus globulus. This is a tree which has attracted an extraordinary amount of attention, and to which have been ascribed almost all the virtues of all the eucalypti, as well as some properties to which none of them has a claim. We have seen that a Committee of Victorians call it an *imported* tree, and I have looked in vain for its name in catalogues of the valuable trees of the other Australian colonies. Hence it is quite an error to term it "the Australian blue gum." Tasmania, the native land of the eucalyptus globulus, possesses a very temperate climate, and though it has some extensive plains, is essentially a hilly country. Not only is the blue gum generally found on the mountains and hilly ground but it has been ascertained that the trees grown in valleys or ravines furnish timber of inferior quality to that from the mountains. Yet the eucalyptus globulous is popularly described as a tree which is remarkably suited for planting in marshy plains in tropical and semi-tropical climates. The explanation of this extraordinary fallacy is no doubt to be found in the statement made by the Victorian Committee, that the name "blue gum" has been applied to nearly every variety of eucalyptus which supplied timber to the Australian market. Again the medicinal properties of the blue gum are much overrated, although it is beyond question that it and several others of the eucalypti do possess such properties. The aborigines of New South Wales made known these properties to the colonists long ago, but the tree which chiefly supplied them with medicines was the *red gum*.

It is not improbable that some of the Australasian trees which have been acclimatized in various countries as blue gum, are those known in Victoria and Tasmania as swamp gum. As much controversy has taken place on this subject, and as the Tasmanian blue gum is one of the most easily recognized of the eucalypti, a description of it will not be out of place. The name of this tree is probably derived from the whitish blue colour of both the leaves and bark in the early stages of its growth. At this period the leaves are sessile and opposite, and are from 3 to 6 inches in length, and from 2 to 3½ inches in breadth. They are round at the extremity, and have distinct upper and under surfaces. The duration of this series of leaves is uncertain, but is generally from two to six years. The second series of leaves begin to appear at the top of the tree and at the extremities of the branches, and the process of changing goes on sometimes for several years till all the leaves of the first series have been displaced. The second series of leaves is entirely different to the first, being petiolate, alternative, and pendulous. They are generally from 4 to 8 inches in length, and from 1 to 1½ inches in breadth, are tapering, curved downwards towards the point or apex, and, like the leaves of other eucalypti, hang vertically. To an ordinary observer the two sides of one of these leaves are precisely similar. When a tree is felled, or when any of the large branches are cut off, the shoots which spring from the stump have sessile leaves similar to those of young plants. The appearance of blue gum trees of from three to nine years of age, or of old trees which have been dressed, is therefore most peculiar, the whitish-blue, rounded, sessile leaves being a remarkable contrast to the dark green, pointed, pendulous ones. I had an opportunity of noticing numerous instances of the former near Hobart Town in Tasmania, and of the latter at Ballarat, where imported blue gums have been planted along the sides of the streets. After the disappearance of the sessile leaves, the blue gum seems to be continually shedding the outer layers of its bark. This generally gives the tree an untidy appearance, as the bark comes off, either in short curled pieces or in long shreds, which frequently hang loosely to the tree. When a strip of the outer layer of bark is peeled off, the surface exposed is of a bright buff colour, which, however, soon changes to grey. The timber of the blue gum is of a yellowish grey colour, of a close, straight grain, and has a specific gravity of 1·05. As the tree grows to an enormous height, the timber can be had in very large pieces. It has a first class reputation, notwithstanding the fact, that it has generally been cut at a bad time of the year, and used without being properly seasoned. It has the disadvantage of being readily attacked by the teredo.

As stated in the foregoing, the encalyptus globulus is not suited to low or marshy land but to hilly ground. Red gum on the contrary flourishes most in rich alluvial soils and in close proximity to water. The best blue gum is found in the very temperate climate of Tasmania, while the best red gum is on the banks of the Murray, in a climate subject to hot winds, and differing only in a moderate degree to that of Northern India. It is therefore natural to infer that while blue gum is not well suited for planting along the banks of canals in Upper India, red gum would be an excellent tree for this purpose. Moreover, for sleepers red gum is scarcely to be surpassed. Its value for this purpose is well understood and appreciated in Australia, and a large quantity from the banks of the Murray was sent to India sometime ago. It may be here remarked that the red gum timber on the Murray has the reputation of being more free from gum veins than that on the Murrumbidjee and in most other localities.

Another tree which would probably be well worth acclimatizing in Upper India is the cypress pine. On the vast plains of New South Wales, sandy ridges are frequently met with, on which only a very scanty crop of grass is seen in the best seasons, yet here the cypress pine not only grows, but flourishes and spreads. It cannot be considered a first class wood, but it is perfectly straight, is easily worked, and is not readily attacked by white ants. If successfully introduced, I believe it would be found more generally useful than any of the common trees of the plains.

For several reasons Australasian timbers have not acquired such a high reputation as they deserve. In the first place, colonial timbers are almost invariably sold, and in the colonies used unseasoned. In the second place it frequently happens that trees of the same kind grown in different places differ widely in their qualities, and that those grown on the plains and more accessible places, furnish a much inferior timber to those grown on hills. This, as already mentioned, is exemplified in the case of jarrah. Again the similarity existing among large groups of colonial woods, affords dishonest persons opportunities for selling inferior timbers instead of others of a superior description, which they resemble. In connection with the facilities for deception, the select committee already referred to, remarked that, "there seems to be but little doubt that many of the varieties of the eucalyptus produce timber so much alike, that one piece cannot well be distinguished from another, even when cut from trees having well-defined botanical distinctions. As a consequence, the timber receives its name more from the fashion of the yard where it is sold, or the saw-mill where it is cut, than from any well grounded knowledge of the particular number of the family from which it has been derived." The timbers of New Zealand and Tasmania labour under still another disadvantage. On account of the inconvenience attending winter work in the forests, the trees are generally felled in the summer months, when the sap is in active circulation. In Australia also little discrimination is used in this matter. The eucalypti, as evergreens, should be felled immediately after the ripening of the seed, and this fact is not so well known as it should be. This carelessness in regard to the seasons at which timber is felled, perhaps accounts to some extent for the serious defect which it is admitted that a large proportion of the colonial timbers possess, namely, that of warping when sawn in half, even though they have been kept for years.

I have in nearly every case avoided giving the botanical names of the various eucalypti, as I found by comparing different reports that different botanists in several important cases, gave different names to the same tree. I may add that in New South Wales there are at least three varieties of the eucalyptus called "blue gum," at least five called "ironbark," at least six called by each of the names "red gum" and "white gum," and at least seven called "box." It is known too that the Tasmanian blue gum was called by one writer "eucalyptus diversifolia," and by some others "eucalyptus pulverulenta." It is sufficiently evident from this, that there is ample room for an endless variety of mistakes, and also that in regard to Australasian trees, *locality* is often of much more importance than name.

I brought some specimens of colonial wood, with me on my return to India, intending to ascertain to what extent they resist the attack of white ants, but have not had time yet to do more than make a ten days' trial. I may mention, however, that specimens of ironbark, red gum, cypress pine, jarrah, kauri, myrtle, blackwood and Huon* pine, after being buried for that period in a white ant's nest where the ants were present in multitudes, remained untouched. (The last three woods are Tasmanian, and the last two are much valued in cabinet-making).

Annexed is given a table showing the strength and elasticity of most of the timbers already described, as compared with English oak. I have reduced the results given in the report of the experiments at the Sydney Mint, to the same form as the tables showing the Woolwich Dockyard experiments, so as to admit of their comparison. The value of the Sydney experiments is greatly lessened by the admission that they were made with unseasoned timber. Ironbark is the only timber which entered into the experiments at both places, and I find that while in transverse strength the

* Called after the River Huon where it is abundantly found.

ratio which it bears to English oak in the case of the seasoned wood, is 1·745 to 1, that of the unseasoned wood is only 1·441 to 1. In regard to elasticity, the difference is much more striking, the seasoned wood giving 2·165 to 1, and the unseasoned 1·172 to 1. The Sydney experiments are therefore valuable only as showing the strength of the timbers commonly to be met with in the Australian markets, and not as an index to the strength of first class specimens. On the other hand, the Woolwich experiments show the transverse strength of kauri one-third less than the result obtained in experiments made at the instance of the Government of New Zealand.

Experiments on Australasian Timbers.

Showing the Transverse and Tensile Strength and the Elasticity, that of English Oak being unity.

Name.	Locality.	Specific gravity.		Relative Transverse Strength.	Order in Transverse Strength A	Relative Tensile Strength.	Order in Tensile Strength B	Relative Elasticity.	Order in Elasticity. C	Remarks.
Ironbark, ..	N. S Wales,	1·14	L.	1·745	2	1·106	7	2·165	7	The experiments bracketed and marked "L" are by the timber Inspector to the Admiralty, those marked "SM" were carried out at the Sydney Mint. The columns marked "A," "B" and "C," show the order in which these timbers stood in a series of experiments on 42 of the best timbers obtainable.
Tuart, ..	Western Australia.	1·17	L.	1·276	11	1·398	2	1·747	12	
Kari, ..	Do.,	0·98	L.	1·069	17	0·934	12	2·093	8	
Kauri, ..	New Zealand,	0·56	L.	0·892	29	0·600	23	1·622	17	
Blue gum, ..	Tasmania, ..	1·05	L.	0·883	30	0·798	18	1·750	11	
Jarrah, ..	Western Australia.	1·01	L.	0·850	31	0·388	35	0·667	37	
Red gum, ..	N. S. Wales,	1·12	SM.	0·992	25 A			0·925	33 A	
Stringy-bark,	Do.,	0·98	SM.	0·933	28 A			0·892	35 A	
Peppermint,	Do.,	0·90	SM.	0·595	41 A			0·567	39 A	
Cypress pine,	Do.,	0·65	SM.	0·595	41 A			0·558	41 A	

These experiments were carried out chiefly at the Woolwich Dockyard.

The numbers to which "A" is attached, show the order in which the timbers experimented on at Sydney would have stood among those experimented on at Woolwich.

H. G. McK.

No. CCXXXVIII.

MEMORANDUM ON THE LAWRENCE AND MONTGOMERY HALLS.

[*Vide* Plates XXXV. to XL.]

By Rai Bahadur Kunhya Lal, *Assoc. Inst. C.E., Exec. Engineer, P. W. Department, Punjab.*

The accompanying *Plates* XXXV. to XL., show the above buildings, well known at Lahore as the "Lawrence and Montgomery Halls."

They are joined by a covered corridor, and are situated in the Lawrence Gardens, the Lawrence Hall fronting the Mall, and the Montgomery Hall facing the central avenue of the gardens.

The Lawrence Hall was built in 1862, from designs by Mr. G. Stone, C.E., and the Montgomery Hall in 1866, from designs by the late Mr. J. Gordon, C.E.

The original vaulted roof of the Montgomery Hall cracked much subsequently, and was considered unsafe.

It was removed in 1875, and replaced with a wooden roof overlaid with galvanized corrugated iron sheets No. 18 B.W.G., and having an ornamental coved wooden ceiling, beautifully painted, and fitted with glass windows, which have a good effect. This re-roofing and restoring of the Hall, has been successfully carried out by Rai Bahadur Kunhya Lál, C.E., Exec. Engineer of Lahore, in 1875-76. *Vide* Professional Papers on Indian Engineering, Second Series, No. CCXXXVIII.

The Lawrence Hall was built chiefly from contributions by the European community of the Punjab, and the Montgomery Hall, from subscriptions by the Native Chiefs, whose names are inscribed on a marble tablet in the building.

The Lawrence Hall measures 65′ × 32′·5 inside, and is chiefly used as an Assembly room for public meetings, and theatrical entertainments.

The Montgomery Hall is 106′ × 46′ wide inside, and is used for Grand Balls and Durbars.

The Lawrence Hall was built as a Memorial of Sir John (now Lord) Lawrence, and the Montgomery Hall in memory of Sir Robert Montgomery.

The Lawrence Hall cost about Rs. 34,000, and the Montgomery Hall, Rs. 1,74,000, as follows:—

	RS.
Original cost of building with vaulted roof, ... (from subscriptions by Native Chiefs).	1,08,000
Subsequent re-roofing and restoration from *General L. Fund*, ...	66,000
Total, ...	1,74,000

The style of architecture of both the Halls is classical, and the particulars of work, are as follows:—

The walls are throughout of pucka bricks laid in mortar, lime plastered inside and outside. The interior and exterior of the Lawrence Hall, and the exterior of the Montgomery Hall, are polished, and jointed in imitation of stone.

The floors are boarded of deodar wood, except those of the corridors and the small rooms attached to the Lawrence Hall, which are of well burnt hexagonal tiles, laid neatly in cement.

The doors and windows are of deodar wood, glazed and painted.

The roofs are trussed, with ornamental wooden ceiling underneath; flat in Lawrence Hall, and coved in Montgomery Hall.

The roof covering of the Lawrence Hall is lime terraced, and that of the Montgomery Hall, galvanized corrugated iron sheets, with perforated ridge ventilation.

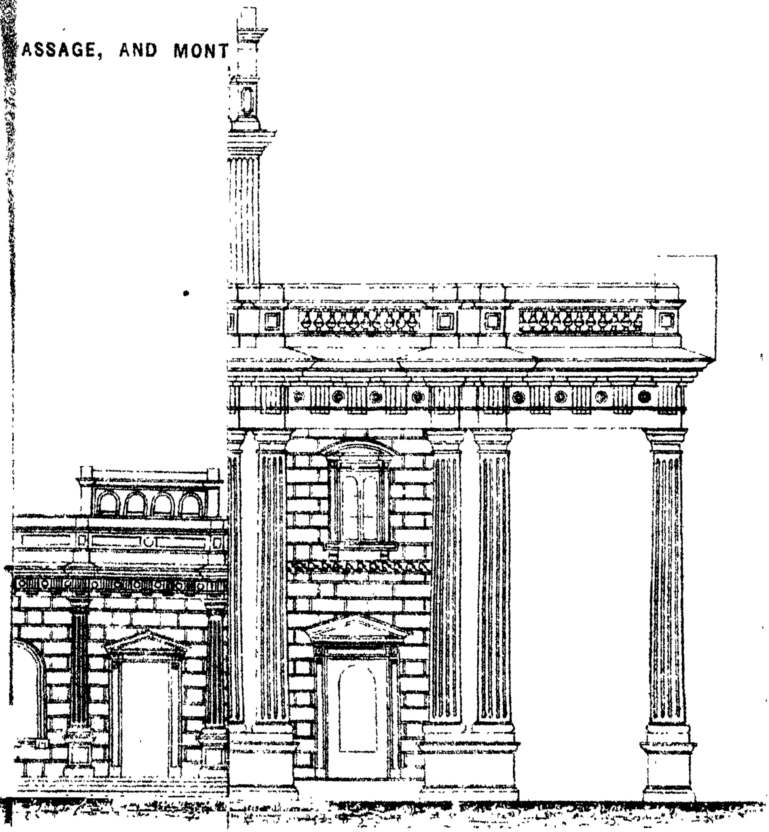
A large space outside both the buildings is metalled with kankar, with a good slope outwards, to lead the drainage away from the buildings.

K. L.

ONTGOMERY

feet = 1 inch.

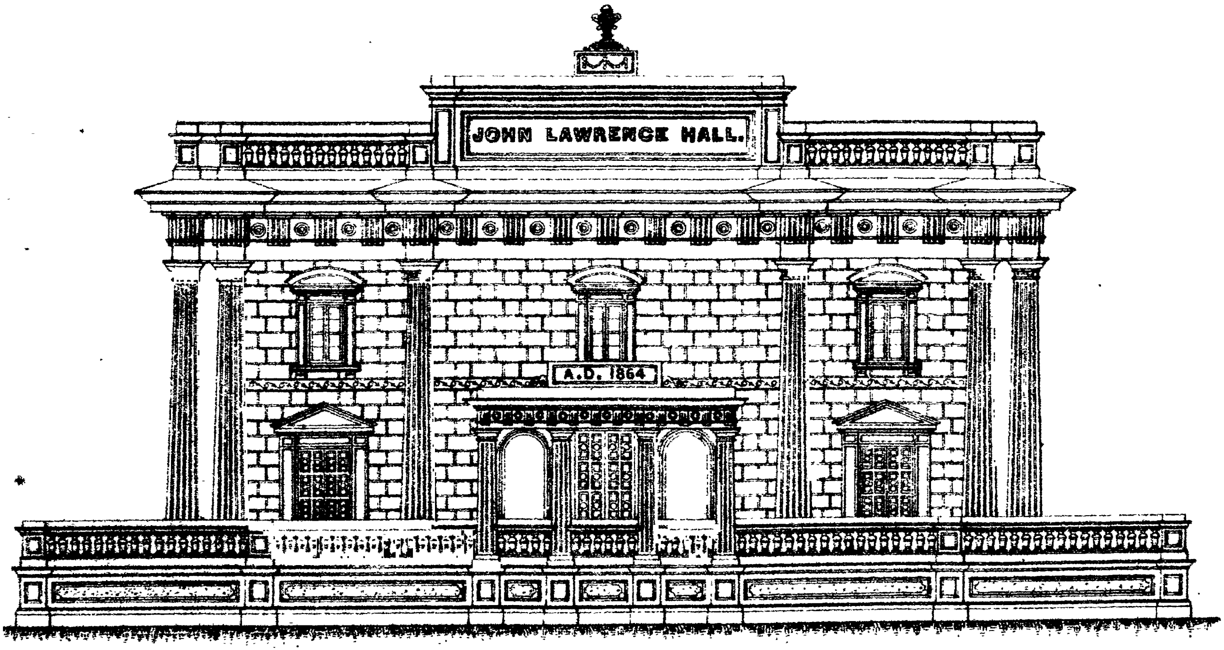
ASSAGE, AND MONT



LAWRENCE AND MONTGOMERY HALLS.

Scale. 15 feet = 1 inch.

FRONT ELEVATION OF LAWRENCE HALL.



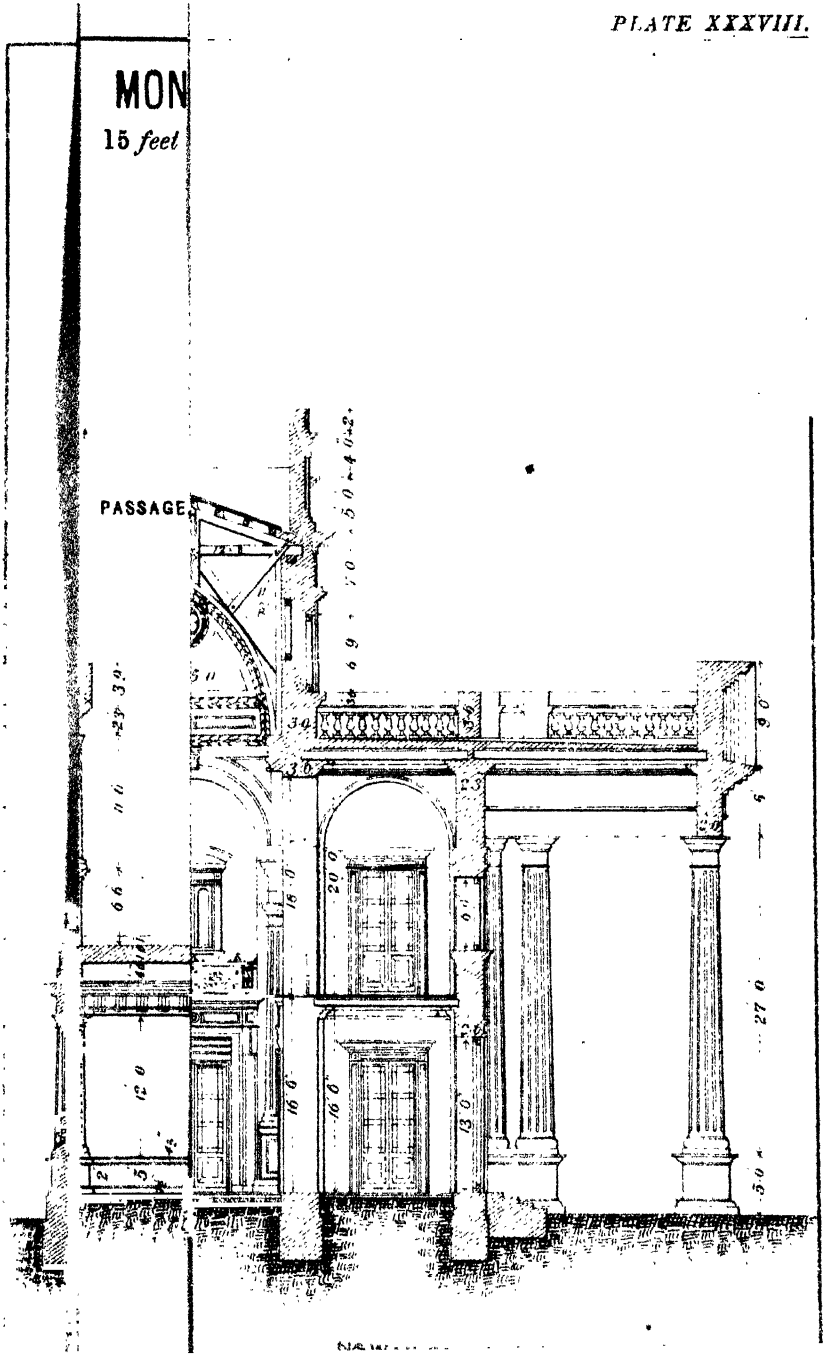

MON
15 feet
PASSAGE
PASSAGE

PLATE XXXIX.

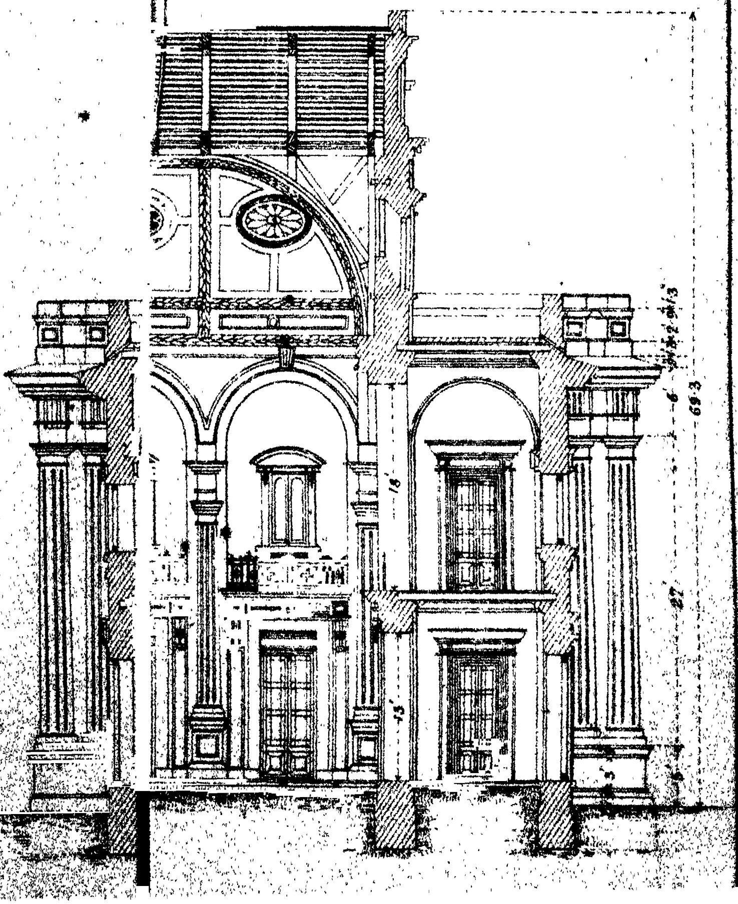
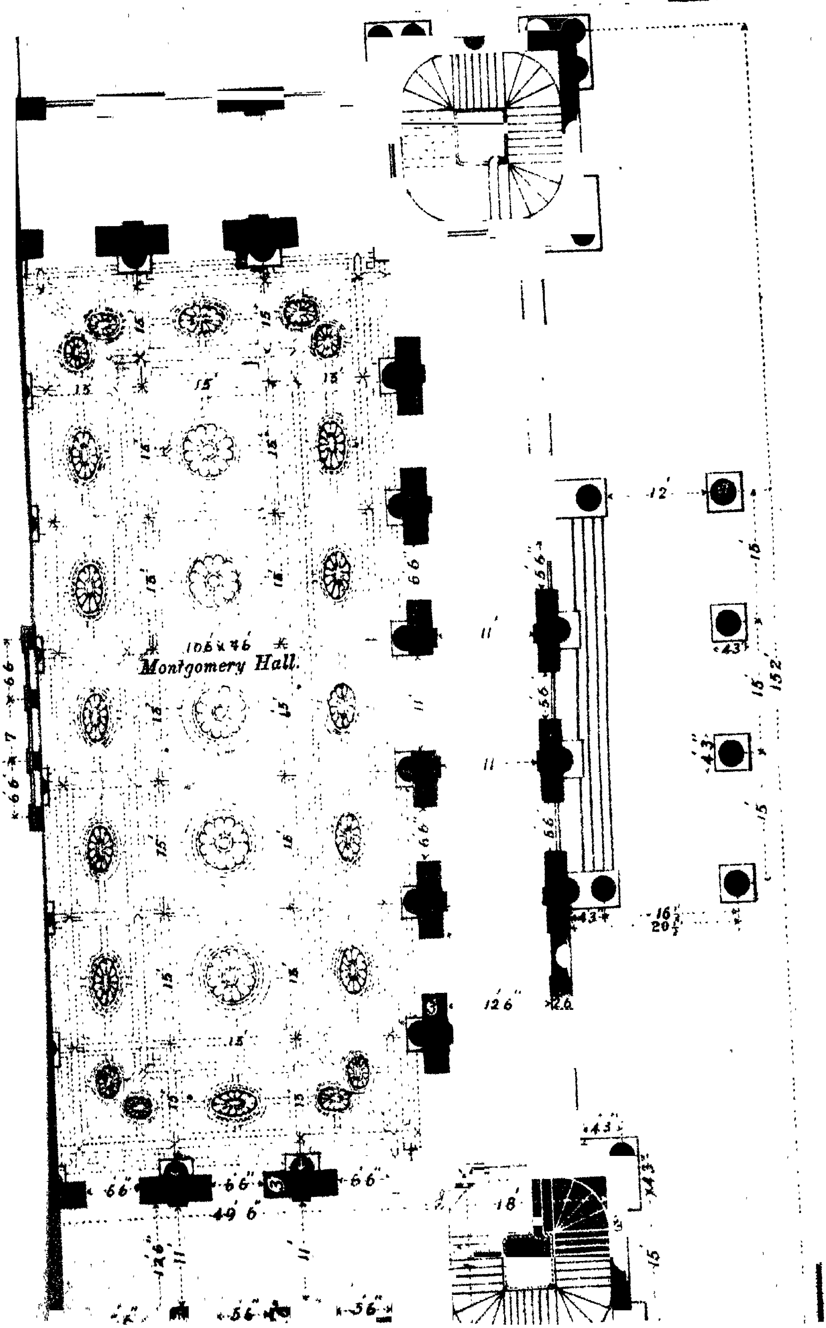


PLATE XL.



No. CCXXXIX.

NEW FEMALE PENITENTIARY AT LAHORE.

[*Vide* Plate XLI.]

By Rai Bahadur Kunhya Lal, *Assoc. Inst. C.E., Exec. Engineer, P. W. Department, Punjab.*

The New Female Penitentiary at Lahore, is built as per block plan accompanying, and the buildings are sufficient to hold 250 Native, and 4 European, prisoners. Of the former, 48 are accommodated in cells, and the rest in wards. Besides the above, accommodation for 8 Juveniles is provided in separate buildings. Wards for 4 European prisoners, 12 quarantine cells for Natives, and quarters for the Matron, Native Doctor, Female Warders, and Guard, &c., are also constructed. All the buildings with the exception of the office, and quarters for the Matron, Native Doctor, Guard, Female Warders, and Guard Room, which are placed outside the jail, on either side of the gate, are enclosed in an enclosure, measuring 770′ × 770′. The enclosure wall is of pisé work, 2½ feet broad and 14 feet high, the corners of the square being rounded off to a radius of 40 feet. The buildings are arranged on the radiating principle, between two circles (an outer one and an inner one) inside the enclosure, the outer circle having a radius of 330 feet, and the inner one of 75 feet, both being connected by an open passage 18 feet inside. There are eight compartments, four of which have a ward in each, for 50 prisoners; two have blocks of solitary cells for 24 prisoners each; one has workshop and cells for 8 juveniles; and one, the largest of all, has a hospital for 24 patients.

The subsidiary buildings are arranged as shown on the plan. The general construction of the buildings is as follows:—

Foundations.—Of concrete 1 to $1\frac{1}{2}$ feet in depth.

Plinth.—Of small native bricks.

Superstructure.—Of sundried bricks. Except door jambs, flat and relieving arches, over doors, verandah pillars and arches, 1 foot under wall plates, and $1\frac{1}{2}$ feet under treads of doors, and other openings, which are pucka, of small native bricks. The outer walls of hospital, barracks, workshops, cook houses, matron's house, quarters for the guard, and office, are faced with pucka bricks and pucka plastered.

Floors.—Of hospital, office, matron's house, and wards for European prisoners, are pucka, roof of all the buildings is flat, supported on deodar beams and rafters, overlaid with bricks and mud, except that of the hospital and barracks, which is made of small native tiles, on deodar trusses, purlins, and battens. Doors of hospital, matron's house, and office, are glazed, those of barracks and godowns panelled, and those of cells are battened, covered with sheet iron, having openings fitted with iron bars, for ventilation.

Openings for ventilation are provided in flat roofs, covered with inverted ghurrahs, and complete ridge ventilation is provided in the barracks and hospital. This Jail is similar to the Montgomery Jail, which was also constructed by the writer, *see* Article No. CXLIII. of 2nd Series. The only new thing in this Jail is the water supply. In other Jails, wells are sunk almost one in each compartment, from which, the inmates draw their supply of water, by means of buckets or pumps, but in this Jail, only one well is sunk in the centre of the inner enclosure, near which, a reservoir is constructed, which is entirely of pucka masonry of small native bricks. Its dimensions are 15′ × 15′ × 5′, and its bottom is 5 feet above the level of the ground. It is pucka plastered inside and outside. A filter $4\frac{1}{2}$′ × $3\frac{1}{2}$′ is attached to the reservoir.

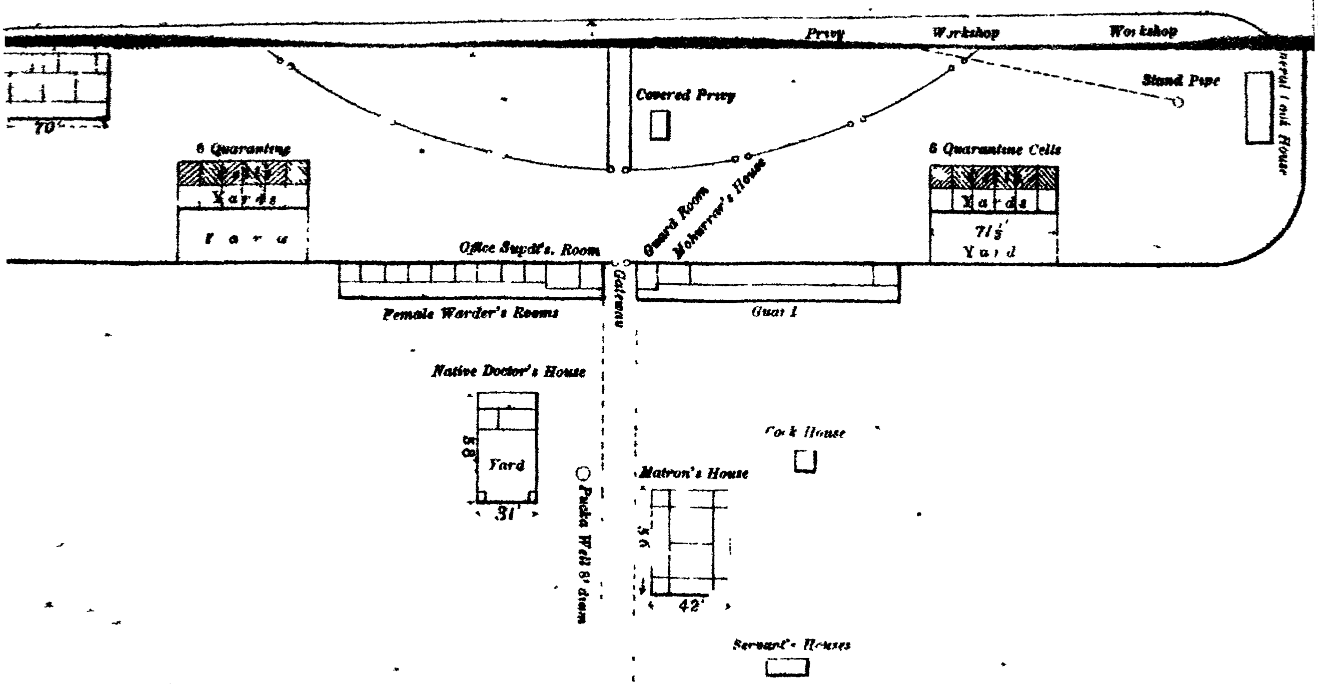
Pipes are laid from the reservoir to the various compartments, which terminate in stand pipes, the tops of which are $2\frac{1}{2}$ to 3 feet above the level of the ground. The pipes consist of best burnt pottery, unglazed, 4 inches in diameter, enclosed in pucka masonry $2\frac{1}{2}$′ × $2\frac{1}{2}$′, and laid 3 feet below the ground. The pucka masonry rests on a bed of concrete, 6 inches thick, and well consolidated. The pipes at the bends consist of "*gharris*" or small "*gharras*" having pipes in the directions of the bends, and the joints of the pipes are secured with fine cement of stone

PLATE XLI.

NEW FEMALE PENITENTIARY, LAHORE.

Scale. 100 *feet* = 1 *inch.*

BLOCK PLAN.



lime, and the whole of the pipes wrapped round with thick coarse cloth, dipped in a hot mixture of fat, wax, oil, and lime, and then enclosed in masonry, which makes the pipes watertight.

The stand pipes consist of small pillars of pucka masonry, having zinc pipes in their middle, connected with the angular pottery pipes below, and terminating, on one side, in a brass tap, which can be opened and shut by turning a handle.

Water from the well is raised by means of a Persian wheel into a small reservoir, from which it passes into the filtering beds, thence into a small tank, and from there into the large reservoir.

The reservoir and filter are covered with a wooden roof, having openings both at the top and the eaves, fitted with wire netting $\frac{5}{8}$-inch mesh, for purposes of ventilation.

The ends of the openings for passing the water from the reservoir into the pipes, are fitted with perforated zinc plates, to prevent any thing from getting into the pipes. The reservoir has a drain at its bottom, for cleaning it, when necessary.

The accompanying abstract gives the quantities of work, the actual working rates, and the cost of the entire work.

Abstract.

c. ft.		RS.
74,214·25	Concrete in foundation, at Rs. 12-6-7 per 100, ...	9,211
2,68,766	Kacha masonry, at Rs. 3 per 100, ...	8,063
89,125	Pisé work, at Rs. 1-15-2 per 100, ...	1,741
1,27,226·41	Kacha-packa masonry, at Rs. 8-13-4 per 100, ...	11,277
1,31,587·14	Packa masonry, at Rs. 19-15-7 per 100, ...	26,289
15,822	„ at Rs. 25 per 100, ...	3,956
2,936	„ at Rs. 30 per 100, ...	881
7,57,955	Earth filling in, under plinth, at Rs. 0-4-0 per 100, ...	2,010
s. ft.		
27,035	Small tiled roof covering, including square tiles and lime, at Rs. 10 per 100, ...	2,703
4,450	Battened doors and windows, at Rs. 0-10-0 per foot, ...	2,781
mds. sr.		
797 1	Ironwork of doors, of cells, and barracks, at Rs. 11-12-4 per maund, ...	9,382
132 35	Iron tie-rods, at Rs. 14 per maund, ...	1,860
c. ft.		
9,632·20	Deodar wood wall plates, kurrees and wood for trusses, &c., at Rs. 1-8 per foot, ...	14,448
	Carried over, ..	94,602

		RS.
c. ft.	Brought forward, ..	94,602
11,245	Deodar wood, wall plates and beams, &c., ...	2,249
s. ft		
20,709	Flat roof covering, 2nd class, at Rs. 8-7-0 per 100, ...	1,655
77,057	Pucka plaster of coping and water-drips, at Rs. 3-15-7, per 100,	3,082
5,668	" " drip cornice, at Rs. 20-10-3 per 100, ...	1,170
2,584	Doors of cells, of kikar wood, at Rs. 0-9-1, per 100, ...	1,473
13,126	Roof covering of sirki and mud, at Rs. 2-8-7, per 100, ..	333
1,980	Bullees for roof, at Rs. 12 per score, ...	1,188
14,319	Tiled flooring, at Rs. 10-8-5 per 100, ...	1,509
900	Brick flooring, at Rs. 15 per 100, ...	135
800	Pucka terraced flooring, at Rs. 8 per 100, ...	64
2,133·3	Half glazed and half pannelled doors and windows, at Rs. 1-0-6,	2,207
1	Pucka well, with reservoir, at Rs. 781, ...	781
1	Pucka well, without reservoir, at Rs. 600, ...	600
	Levelling site and clearing rubbish, &c.,..	211
	Compensation for land, ...	1,037
	Cost of three centerings for arches, at Rs. 250 each, ...	750
r. ft.		
1,152	Pucka cornices of bridge on the road leading to the new Female Penitentiary, at Rs. 0-6-0 per foot, ...	433
14	Curbs for wells of do. do., at Rs. 20 each, ..	280
c. ft.		
16,079	Brick metalling round the buildings, at Rs. 2-15-2 per 100, ..	474
9,401	Kankar metalling, at Rs. 8-5-5 per 100, ...	784
3	Entrance gates, at Rs. 250 each, ...	750
r. ft.		
2,132	Earthen pipes enclosed in pucka masonry, at Rs. 19-15-8 per 100,	426
c. ft.		
4,85,671	Filling ditch and hollows, at Rs. 2-14-0 per 100, ...	1,403
s. ft.		
25,269	Pucka plaster of buildings, at Rs. 3-12-3, ...	952
	Petty items, under Rs. 200 each, ...	1,156
	Contingencies, ...	5,761
	Total, ...	1,25,465
	Deduct prison labour, ...	4,104
	Grand Total, ...	1,21,361

K. L.

No. CCXL.

PROTECTION OF BUILDINGS FROM LIGHTNING.

By Dr. R. J. Mann, M.D., F.R.A.S.

[*Read before the Meteorological Society*, 28*th April*, 1875.]

In bringing the subject alluded to in this communication under the notice of the Society of Arts, the author intends to mark the present state of exact science in regard to the matter, and to describe as compactly as may be done, consistent with intelligent and sufficient explanation, the way in which buildings may be most conveniently and certainly secured against damage from lightning.

As, however, it is the purpose of this paper to deal intelligently, rather than dogmatically and prescriptively, with the theme, attention must in the first instance be drawn to certain established principles of electrical science which underlie the explanation that has to be given. This is essentially necessary in this case, because the most absurdly inefficient, and often dangerous, attempts to protect buildings from lightning are continually encountered, and because these constructional blunders can almost always be directly traced to ignorance or misapprehension of simple and well-ascertained electrical laws.

It is a familiar and at the same time an all-important fact, that the electric force is transmitted readily through certain kinds of bodies, such as metals and moist substances, which are therefore termed conductors; and that it is transmitted with comparative difficulty through other substances, such as glass, gutta-percha, and resins, which are called "insulators."

It should be, however, understood that the rigidly scientific interpretation of this difference is that dissimilar bodies, of whatever kind, vary in the resistance which they offer to the passage of the electrical energy, and that that passage is effected easily and readily when the resistance is small, but slowly and with difficulty when the resistance is great. In strict accuracy, there is probably no such thing as an absolute electrical insulator. If a rod of glass and a rod of metal be presented to an excited electric, the electrical charge will escape through both, but very nearly the whole will go through the metal, and almost none will go through the glass. The precise proportion that will traverse each will be determined by the relative powers of resistance inherent in the glass and in the metal. The matter is spoken of, in loose terms, as if all the discharge went through the metal and none through the glass; and this answers very well for purposes of familiar explanation, because the quantity that escapes through the glass is so very trifling, that it is incapable of producing any perceptible mechanical effects.

All forms of electrical machines which are constructed for producing artificial manifestations of electrical force, are produced by so arranging insulators and conductors, as that the force may be generated on the surface of the insulators, and then collected and conveyed by the conductors in an accumulated form, the conductors that effect the accumulation being in their turn insulated, so that the gathered force may not escape as immediately as it is engendered, and therefore before its mechanical or other obvious effects can be manifested and examined.

But the action of artificial electrical machines is also in a very large degree dependent upon another fundamental law of electrical action which is less easy to explain, but which is of such universal importance, that it must be thoroughly understood and indeed be kept constantly in mind, as the great ruling power in most of the phenomena that have next to be considered. The influential law which is here alluded to is the one which is involved in all that is recognised as "electrical induction." Whenever an insulated conducting body is brought near to another electrically-excited body, but in such a way as that it is not in actual contact with it, the insulated conductor immediately shows signs of being as it were sympathetically affected by the mere presence of the excited body. When the excited body is withdrawn, the sympathetically-aroused excitement in the insulated conductor subsides; when it is brought back into close neighbourhood, the excitement immediately returns. This is what is called "induced electrical action," or "induced electricity."

The effect is very easily shown, in a suitably dry atmosphere, by placing an insulated conductor near to, and not in contact with, the excited prime conductor of an electrifying machine, and then taking the induced electricity from the separate conductor by means of a small carrier of copper foil, fixed upon the end of a glass or ebonite handle, and communicating the charge to the cap of a gold-leaf electrometer. The leaves of the electrometer immediately diverge, manifesting the presence of the electric force that is communicated to them. The experiment may be very pleasingly varied by making a living human body the seat of the inductive disturbance; if an operator stands upon a glass-legged stool with the finger of one hand touching the cap of the gold-leaf electrometer, and with the other arm stretched out so that an assistant can bring a long well-warmed glass jar that has been rubbed with silk and amalgam, and in that way electrically excited, over the extended arm and about a quarter of an inch away from it. Electrical disturbance is immediately produced inductively in the body of the operator, and made manifest by the divergence of the gold leaves of the electrometer; and the divergence is produced and subsides over and over again as the excited glass jar is brought near to the arm, or is taken away. The explanation which science offers of the very remarkable phenomenon, is to the effect that the insulated conductor has intrinsically mixed up with its own molecules two distinct kinds of electrical influence, be that what it may, whether essentially a specific molecular condition, as is most probable, or some superadded, and so-called, imponderable agency, and that these two kinds of electrical force are quiescent and inappreciable, so long as they are equally balanced, and as it were united throughout the entire superficial mass of the conductor, but that they become operative and appreciable whenever the two kinds are torn apart and held asunder. The mere approach of the excited body effects this disturbance of the natural quiescent state, and this tearing asunder, and one of the kinds is then accumulated at one end or side of the conductor, and the other kind is collected at the opposite end or side. There is a neutral point nearly midway between, but nearer to the end that is towards the exciting body, at which no electrical influence of either kind is manifested. If the exciting body is itself positively or vitreously electrified, the end of the excited body which is nearest to it is negatively excited, and the opposite end is positively excited; the terms positive and negative being here understood simply as convenient terms invented to distinguish the two different kinds of electrical state or force.

The test of induced electricity, viewed in contradistinction to a communicated charge, is virtually that the state is called up and removed merely by the nearness and withdrawal of an electrically-excited body. If a charge of electricity were communicated from an excited body by a momentary contact, the electrical condition would continue in the insulated conductor after the exciting body was taken away, instead of instantly disappearing as it would in the case of induced action. Also the same kind of electrical force would then be found at both ends and all over the insulated conductor.

But here there arises a very curious, and again most important, consideration. Under the circumstance of electrical excitement being called up in an insulated conductor by the near approach of an electrically excited body, the opposite ends manifest opposite electrical conditions, and on the removal of the excited body the induced action disappears. If, however, when the disturbance has been inductively produced, the insulated conductor is momentarily touched at the far end by another conducting body in contact with the earth, as the finger of an operator, the inductively separated force belonging to the insulated conductor, which is of the same kind as that of the exciting body, rushes off to the earth; and then when the exciting body is removed, the insulated conductor does not return, as it would otherwise have done, to its natural and quiescent state, but manifests an electrically excited condition all over its surface, of a kind opposite to that of exciting body. It behaves, indeed, in all particulars as it would have done if an actual charge of that opposite kind of electrical force had been communicated to it by contact with a similarly excited body.

When the glass cylinder or disc of an electrical machine is positively excited by friction against the rubber, the metal points, which are in metallic communication with the insulated prime conductor, and therefore the conductor itself, become inductively electrical. The negative electricity of the inductively disturbed conductor flows off from the points to the glass to saturate its positive disturbance, and the prime conductor is consequently left overcharged with its own abandoned positive force. That is the explanation of the way in which streams of positive electricity are generated in the prime conductor of a machine by continuously rubbing its glass cylinder, or plate, against a mercurialised cushion.

It will be understood that the kind of electrical force which is manifested when a glass rod or surface is called positive or vitreous electricity, and that the opposite kind which is produced when sealing-wax or other resinous substance is rubbed, is called negative, or resinous electricity. These names were first used by the early discoverers in electrical science, and no more convenient or expressive designations for the conditions which they represent have since been found.

It has been shown from the long-continued and most carefully conducted observations of De Saussure, Ronalds, Quetelet, and Lamont, that in dull fine weather, the surface of the earth is always in a negative state of electrical excitement, and that the surrounding air is commonly in a positive state. M. Peltier attributes this positive tension of the air to the state of the inter-planetary space. He considers that the vacant spaces of the universe are in a constantly positive state, and that the surface of the planetary spheres is kept in the opposite state of negative excitement by the influence of induction. In the absence of any more definite evidence on this point, it is, however, perhaps more philosophical and satisfactory to consider, as many other authorities do, that the positive state manifested by the air is effectively seated in the particles of moisture contained in the atmosphere, and that it has been carried up with them from the earth when they rose through evaporation.. M. Becquerel has shown that the surface of the sea, and the air lying immediately over it, is as constantly in a state of positive electrical excitement as the land is in a state of negative excitement. The fine weather positively electrical state of the air only appears over the land at some considerable elevation. This also, it must be added, is influenced in some material way by the varying positions of the sun. It is strongest in the season of short days, and weakest in the season of long ones; and there are also in every day two periods of comparatively strong, and two of comparatively weak, electrical excitement, which recur approximately at the same hours of the day and night. The positive electrical state of the higher regions of the atmosphere is also considerably diminished by deposits of moisture in the air, and with very copious and rapid deposits sometimes disappears altogether, and becomes even replaced by the opposite negative state.

It may, perhaps, be well here to remark incidentally that the distinguished electrician Auguste de la Rive inclined to attribute the electrical states, which ascend to the clouds upon the aerial vapours, to chemical changes, brought about by the reactions of the inner surface of the earth's solid shell and the subjacent molten rock with probable infiltrations of the waters of the sea into the subterranean alembic. Chemical changes of the surface-material of the earth, and the composition and decomposition of complex surfaces, no doubt have to do with electrical manifestations and disturbances. But it must also be added that human science has not yet penetrated very far into this region of research. It is, perhaps, the one field that is most immediately open to further investigation.

We are, nevertheless, after this brief glance that has been given to preliminary considerations, now fairly in a position to understand that there are present in the cloud-sustaining air all the conditions which are essential to convert it into a mighty machine for the production and accumulation of electric force. The broad masses of insulated cloud are conductors ready to receive large charges of the developed energy; these are the prime conductors and the Leyden jars of the apparatus. The surrounding spaces of clearer and drier air are the insulators that imprison the accumulating charge. And the vapours that ascend from the earth and drift in with the winds from side regions, are the carriers and feeders of the charge; they play the part of the revolving cylinder or plate. All that is necessary for the production of a thunder-storm under these arrangements is the rapid agglomeration in one spot of very dense clouds—a result which can more easily be brought about in summer than in winter, because then the air is more abundantly charged with water, and because then a very slight degree of chill suffices to throw down copious deposits of the aqueous load. When a strong current of very abundant vapour ascends from a tract of moist and heated land into the higher regions of still calm air, where there is no moving wind to scatter the condensing vapours as they form, a powerful electrised mass of dense thunder-cloud is as sure to be formed as the prime conductor of an electrical machine is sure to become charged with sparks when its cylinder or plate is rubbed against the cushion. It will be here understood, however, that the real function of the cloud is simply the bringing into continuous electrical communication a wide stretch of electrically-charged air. It is the air-substance which receives the electrical force, and the condensed and closely-packed moisture of the cloud merely enables large tracts of it to come simultaneously into play as a continuous and connected charge. Sir William Thomson especially insists upon the fact that clouds are not indispensable to aerial charges and disruptive discharges of electricity. They properly act to the aerial charge exactly as the metallic coating of the Leyden jar acts to the charged glass. They facilitate the concentration of the full force of the entire connected charge upon one spot.

When a charged thunder-cloud is thus generated in the upper regions of the air, and hemmed round by its circumscribing insulation, all the complicated phenomena of induction immediately appear. Other neighbouring masses of insulated and conducting cloud have their quiescent state sympathetically or inductively disturbed, and the primary mass of the storm-cloud being positively charged, their nearer parts manifest negative energy, and their further parts the positive state. If an intervening layer of other cloud floats between the storm-cloud and the earth, its bottom becomes positive towards the negative earth, and its top negative towards the storm-cloud. The inductive influence of a highly-charged thunder-cloud is extended in this way to almost incredible distances, amounting even to several leagues. Very commonly the inductive power of clouds quite on the far horizon is indicated by delicate instruments, like the atmospheric electrometer of Peltrier, or Gourjon, in which two or three thousands turns of a wire brought from a metal globe, or a tuft of fine platinum wires, raised high in the air and continued to the ground are wound on the way round a sensitive and delicately-poised magnetic needle. The air-space surrounding a positively charged storm-cloud is always in a state of negative excitement from the influence of induction. When a storm-cloud drifts over a fixed station, a delicate electrometer first indicates the presence of negative electricity as this approaches, it then shows positive electricity while actually engaged with the cloud, and then again manifests negative excitement as the cloud passes away. When a storm-cloud hangs low over the earth, the negative reaction of that part of the ground is very largely intensified by induction, and the positive charge of the lowest portion of the cloud is in its turn also strengthened by the same agency. Storm-clouds are for the most part positive in their actual communicated and accumulated charge. But it sometimes happens that negative vapours are poured out suddenly from the moist heated ground for some unascertained reason, and then negatively active storm-clouds appear. It has been found that hail-storms are generally connected with these abnormal negative cloud-charges.

When a charged thunder-cloud hangs low over the earth, all projecting bodies rising from the ground are most powerfully influenced by the inductive action, and conducting bodies, such as rods, tubes, and sheets of metal, more powerfully than bodies that have less conducting capacity. All such prominent bodies become highly charged with electrical force of an opposite character to that which is concentrated in the cloud, and which strains to escape to the cloud, at the same time that the electricity of the cloud in its turn tends to escape to them. If no passage of the electrical force takes place between the prominent objects and the cloud, it is simply because for the time being the intervening layer of insulating air affords a sufficient resistance to prevent such occurrence. The cloud is then drawn nearer to the earth by the influence of the mutually tending forces, and, perhaps, is at the same time driven into closer propinquity by the wind, until at length the narrowed resistance of the air is overcome by the simultaneously heightened tension of the accumulated electricities. The lightning stroke then flashes between, and the tension is lessened. In this lightning stroke some positive electricity passes from the cloud to the earth, and some negative electricity from the earth to the cloud. The positive escape releases the negative induction of the objects placed on the ground, and the negative escape saturates and satisfies the positive charge of the cloud. In some circumstances the lightning stroke may take place through very large distances—according to Delisle and Petit, as large as even nine and ten miles—especially if a kind of interrupted trail of partially conducting material is laid along its course. But for ordinary circumstances, the striking distance varies between 650 and 6,500 feet.

When the lightning stroke finally takes place, it of necessity occurs through the line of smallest resistance that is open to it. It invariably falls upon the most prominent conducting substances that are offered, and this constitutes the provision upon which all proceedings for protection against lightning are primarily based; and it should here be understood that there is no doubt or uncertainty of any kind involved in this part of the consideration. An electrician will present a metal rod and a glass rod to the charged conductor of an electrical machine in the positive certainty that the spark will dart out upon the metal, and not upon the glass; and he will perform the experiment a thousand times without any variation in the result. That the lightning will strike upon a good conducting surface in preference to a bad one, provided the entire course of the discharge through the good conductor is an open and an easy one, is as certain as that a ball of metal will be struck by the spark of the electrical machine in preference to a lump of resin or glass.

But there is a second consideration of scarcely less consequence in the arrangements for defence against injury from lightning, namely, the well-proved fact that even the most powerful electrical discharge passes through substances affording an easy way, and offering small resistance without disturbing the molecular condition of those substances in the slightest degree. It is only when it has to force its way through badly conducting bodies, which afford considerable resistance to the passage, that it effects destructive mischief, which it then brings about by severing their component molecules, so as to split up and disintegrate the mass. When good conductors are of very small dimensions, they, in their turn, also afford considerable resistance to the transmission of the electric force. But in their case the resistance tells, not in shattering the resisting mass, but in heating it. A very fine wire is rendered red hot by the passage of a powerful electrical discharge, and it may, if the discharge is energetic enough, be melted, and so disintegrated by the passage. But it is never explosively shattered, as bad conductors are, under any circumstances.

The lightning which is seen in a dark sky flashing between a storm-cloud and the earth, or between two storm-clouds, is a trail of intense sharply-defined light, often appearing to move along a zig-zag course, and occasionally dividing into two, or possibly into three, branches. The duration of the light does not exceed the thousandth part of a second. This has been very ingeniously demonstrated by Professor Wheatstone, by causing a wheel with a number of spokes to rotate so rapidly that the spokes disappear, unless when the wheel is lit up by a flash of lightning, when the spokes of the rotating wheel are seen distinctly, and the wheel itself looks as if standing still, because the illumination is for so brief a time, that it has ceased before the advancing spokes have materially changed their position. Professor Tyndall shows this result very prettily in his lectures at the Royal Institution, by lighting up the rotating disc by the successive discharges of a small Leyden jar, so placed that the spark occupies the focal point of a concave mirror looking towards the disc. The disc is rotated rapidly by a multiplying wheel, and the electrical machine is worked continuously, so that the Leyden jar keeps on discharging itself by overflow at repeated intervals. With each discharge the radiant spokes of the disc present themselves to the eye as if they constituted for that instant a stationary object. The exact rate of the rotation of a wheel being known, it is easy to calculate the duration of a light which lasts only long enough not to allow the onward movement of a spoke to be discovered. The lightning flash is most probably often formed of numerous successive discharges following each other in the most rapid succession, and when this is the case, the duration of the light may be somewhat prolonged. The author of this communication has distinctly seen the lightning in the subtropical districts of Southern African quivering for quite notable instants from this cause, and seemingly widened into straps or bands, having an appreciable breadth. The broad sheets of lightning-illumination, which are commonly observed during the prevalence of a storm, are, however, quite distinct from these lines of luminous discharge. They appear to be due to the leaping of electric discharges of much lower intensity, from cloudlet to cloudlet, as the re-distribution and re-adjustment of the electric force takes place within the constituent masses of the cloud, exactly as happens in the "spangled pane" of the electrician, when the electric discharge is made through the diamond-shaped masses of tinfoil distributed upon glass. The sheet lightning of the horizon is merely the reflection of the light propagated from discharges that are taking place beyond the visible part of the earth's curvature.

There is yet another form of lightning which is of exceeding interest to the electrician, and which is characterised by prolonged endurance and slow movement. This form has the aspect of a ball of fire, often as large as a child's head, which travels slowly and perceptibly along the ground and finally explodes like a bomb-shell, with a loud detonation, scattering zig-zag rays in all directions. These ball lightnings have been watched in their slow march through the air, even as long as eight and ten seconds, and they constitute the kind of lightning that has been most commonly noticed in the interior of houses. They are essentially the lightnings that "disappear up the chimney!" Their true character is, perhaps, yet but imperfectly understood. They certainly differ in essential particulars from the ordinary lightning stroke. They are not electrical discharges pure and simple. Auguste de la Rive inclined to consider them of the nature of compact balloons of explosive gas generated by electrical agency, and shining by inherent luminosty before being finally exploded. Mr. Varley suggested the very ingenious probability that the ball is really a luminous brush discharged from a negatively charged cloud, leading gradually up to the final burst, and moving slowly forward with the charged mass, of which it is the escaping terminal.

The luminous line marking the course of a lightning discharge is really a "crack" produced in the resisting substance of the air when the pent-up and accumulated force finally breaks a way through the resistance. Sir William Thomson speaks of it as being as much a crack as the fissure made by the escape of an over-intense charge through a weak point in the glass, the only difference in the two cases being that the crack remains in the glass, but is immediately effaced in the substance of the air. "The path is prepared beforehand by induction." Mr. W. H. Preece has very graphically and admirably expressed the actual state of the case in an excellent paper read in 1872, to the Society of Telegraph Engineers, in which he says: "The particles of air or other matter in the path are raised to such a high state of polarisation, that they are in a state of 'tottering equilibrium,' and the slightest acquisition of force or diminution of resistance, either by the approach of the conductor or increase of quantity, destroys this condition, and we have a discharge with all the effects of light, heat, and mechanical energy. A ship sailing calmly over the ocean, a moving railway-train, a horseman galloping home for shelter from the approaching storm, may prove the last straw to break this camel's back."

The light which is seen along the course of a discharge of lightning is unquestionably incandescent matter distributed along the track. This is now definitely proved by the employment of the spectroscope. M. Fusinieri, who gave much attention to this bearing of the subject, had, however, arrived at this conclusion long before the spectroscope was known. He satisfied himself that lightning always contains material substances, and supereminently iron sulphur, and carbon in a state of great division, and also of ignition and combustion. M. Fusinieri conceived that the lightning derived this substantial pabulum of its fires from the molecules of these substances that are always floating about as impalpable impregnations in the air. But it is most probable that particles are taken up by the electric discharge from the conducting bodies that form part of its course, and carried along with it. Numerous very curious instances of this absorbing and transporting action are on record. The remarkable case spoken of by M. de la Rive, in which a gold bracelet was taken up from the arm of a lady closing a window during a flash of lightning, without doing her any material harm, is well known. There are instances in which particles of gold seemed to have been transported through the actual substance of thick plates of silver. The removing of the gilding from the frames of pictures by lightning is of frequent occurrence. The author of this paper remembers one case in which the particles of gold had been stripped away from the picture frames in a room that was damaged by lightning, and attached to the walls in spangles at different places. One very curious instance of the influence of the electrical discharge upon metallic masses was brought under the author's notice by his friend Mr. Shepstone, the Secretary for Native Affairs in the Colony of Natal. A settler's homestead, known as the "German House," on the road leading from the seaport to the capital, was struck by lightning, and burnt down. In the situation of a box which had contained money, there were found afterwards lumps of metals formed by the fusion of gold and silver coins. But near to these were a sixpence and a half-sovereign lying face to face, which had been both drilled with a large hole, and at the same time firmly soldered together round the circumference of the hole. The stamp mark in the sixpence was entirely effaced. It is only, however, when metallic substance is in comparatively small mass, or when it forms the termination of a conducting track, upon which a concentrated charge is received, that this disintegration and absorption of metallic bodies occurs. The electric discharge passes through a sufficiently large metallic mass without producing any molecular disturbance, or manifesting any mechanical effect at all.

We are now in a position to return advantageously to the consideration that when a lightning discharge falls from a charged cloud to the earth, it of necessity takes the line of least resistance that is open to it, whatever that may be, and if that line lies along sufficiently large and absolutely continuous metallic substance, the effective resistance to its passage is so small, that no mechanical violence or heating effect of any consequence, ensues. This, therefore, at once indicates what the first expedient in providing artifical protection from mechanical injury must be. A continuous rod of good conducting metal must be carried from the top of the building to the ground. Then when the stroke of lightning chances to fall upon the building, it goes by the easy way, and flows harmlessly and silently through the metallic rod to the earth, and the less perfect conducting materials of the house, such as bricks, mortar, cement, and wood, are not touched. In order, however, that this desirable result may be brought about, it is essential that the metallic rod shall be large enough to carry quietly and harmlessly the largest discharge that may have, under any circumstance, to pass through it. As a rain-water pipe must be made large enough to carry safely away the largest rainfall that can occur if flooding is to be avoided, so the lightning conductor must be made large enough to carry the heaviest lightning that can strike. And it is even more important that this should be secured in the case of lightning than in the case of rain, because an overflow of fire is a more serious matter than an overflow of water. Some electricians consider that an insufficient lightning conductor is better than none at all, because there have been instances again and again where buildings have been saved from mischief on the discharge of lightning, although the lightning conductor that has effected their protection has been burnt up and destroyed. As in such cases, however, a new lightning rod has to be immediately supplied, it would have been obviously better that the conductor of double capacity should have been erected in the first instance. The author of this paper must also add that he has some reason to look upon the conclusion itself with doubt. There is always danger from fire if a lightning conductor of insufficient dimensions happens to be carried along near combustible materials. The lightning stroke is certainly more likely to fall where a lightning conductor, of whatever kind, is placed, than it would be if there were no such appliance. The lightning conductor in such circumstances, may be "the slight acquisition of power which destroys the tottering equilibrium; the last straw which breaks the camel's back," alluded to by Mr. Preece. There certainly is as much danger in the interpolation of a lightning rod in such tottering equilibrium as there would be in "a horseman galloping along over the ground." What the damage is that a conductor of insufficient size may effect is well illustrated in the practice of firing charges of gunpowder in mines by the platinum fuse. A fine wire of platinum is made part of a current of electrical communication in the midst of a charge of gunpowder. When a current of electricity is passed through the wire it becomes red hot, on account of not having sufficient size to convey the electricity without derangement of its molecules, and the red hot wire fires the gunpowder. If the platinum wire had had the thickness of a pencil, instead of a hair, the same charge of electricity would have passed without the explosion of the gunpowder. Another very telling illustration is supplied by the lar change, from the frequent passage of strong currents of electrical force, which materially affects its conducting power. It must also be remarked that copper is a very much better conductor than brass. Copper costs about one-third more than brass, but it transmits electrical currents eight times as well. Messrs. Sanderson and Proctor, of Huddersfield, and of 18, Queen Victoria Street, have recently contrived a copper tape, or strap, for lightning conductors, which costs about one shilling the foot, and which is so flexible, that it possesses in a very considerable degree the advantageous properties of rope. It can be bent round the inequalities of a building with the utmost facility, can be manufactured in continuous lengths to any extent, and can even be coiled for convenience of transport. This copper tape is three-quarters of an inch wide, and an eighth of an inch thick, and therefore contains a sectional area of a little more than a tenth of a square inch of solid metal. This will most probably be found to be ample for all ordinary purposes, and it can, of course, be readily doubled in any case where lofty buildings have to be protected.

The French electricians, who are unquestionably very high authorities in matters of this class, commonly employ metallic ropes, in preference to bars, for the main stretch of the conductor, because they possess a larger sectional area than solid rods of the same diameter, are more easily placed, and adapt themselves to irregularities of structure without the trouble of forging, because they can be readily made of any continuous lengths that can be required, and in the case of iron, can be easily galvanised, and because they are so supple and more manageable. They consider that an iron cable should have a diameter rather more than twice and a half that of a copper cable (27·3 millimetres against 1 centimetre) to have the same efficiency. M. Callaud, an eminent French electrical engineer, who has very recently printed an excellent book on the "Paratonnerre," records that a rope of copper, four-tenths of an inch (one centimetre) in diameter, employed as a lightning conductor at the Church of Sainte Croix at Nantes, and which was made of seven strands, having each seven threads of wire of a gauge of 0·039 of an inch (one millimetre) in diameter, had certainly transmitted several very heavy electrical discharges, without suffering any injury in its own substance, and that a similar rope of one-fifth smaller diameter (8 millimetres) previously employed, had been injured by lightning discharges. Copper bars a fifth of an inch (exactly 5 millimetres) have been know to be as much injured by a single storm, as by ten years of exposure and rust. M. Viollet Leduc, on the other hand, states that copper ropes seven-tenths of an inch (18 millimetres) in thickness, were burned at Carcassone. From a consideration of these facts, and some others of a similar character, the French electricians of the present day employ ropes of copper of from four-tenths to eight-tenths of an inch (one to two centimetres) for each 82 feet of height. Mons. R. Francisque Michel, who has printed an interesting notice of the faulty state of the lightning defence of the public monuments of Paris, with some allusion to the views of M. Callaud, in *Les Mondes* of October 1874, considers that a rope of galvanised iron wire should have a diameter of eight-tenths of an inch, to afford efficient protection under ordinary circumstances. M. Callaud prefers that metallic ropes should be constructed upon hempen cores, on account of the greater pliability which this contrivance gives. It has been already observed that lightning conductors require to be of larger size in proportion to their length. The law which rules this proportion is simply that the facility of electrical transmission in any conductor is in the exact ratio of the coefficient of the conductibility of the metal of which it is composed, multiplied by the number representing the section of the rod, and then divided by the number representing its length. The durability of any rod is, in general terms, in proportion to the square of its diameter. M. Melsens, a high French authority, prefers that there should be several conductors of small size, rather than one large one; and it is at any rate generally agreed that a large building should be furnished with several conductors, and that when several conductors are combined into one stem, that stem must be of a size sufficient for the safe transmission of all the electrical force that can be furnished to it by the contributory branches.

If it so happens that metallic cables have to be joined, the individual wires of the connected ends must be untwisted, and spliced or mingled together, and then be bound tightly round with wire, in such a way that the whole can be dipped into melted solder, or solder be carefully run in over a fire. Cables may be satisfactorily connected with rods by turning a spliced loop upon their ends in this way, and by then binding this loop in upon the rod by means of strong screw nuts. Mons. Michel, in speaking of the need of renewing the efficiency of the public lightning conductors of Paris, makes the excellent practical suggestion, that the ends of rods requiring to be spliced in continuous electrical communication, should have plates of soft lead firmly nipped in by screw power between the ends that are to make contact, the entire joint being afterwards enclosed in a sufficient investment of solder.

The disintegrating energy of an electrical discharge is mainly expended upon the extremities of a conductor. It effects the most marked molecular disturbance on the part where it first falls, where most probably the first meeting of the two antagonistic forces occurs, and where the terms of the new alliance have to be arranged, and also on the part by which it has to issue from the conductor to the ground—the great natural reservoir of the reserve of the energy. On this account, lightning conductors require to be expanded and amplified both at their summits and at their roots or base. The French Academie des Sciences directed that the top of the conductor should be a bar of iron two and a quarter inches in diameter, whether square or round, tapering up to a blunt conical copper point, shaped to an angle of 30 degrees. The pointed termination of the conductor is a matter of some practical consequence, because it establishes a slow and gentle discharge of an accumulation of electrical force at high tension, as is illustrated in the ordinary experiment, where the charged conductor of an electrical machine is quietly discharged by the presentation of a sharp needle to it. De la Rive held that a metallic ball was quite as efficient for an upper terminal as a point. But when a great number of lightning conductors are brought near together, as in protecting the buildings of an extended town, there is no doubt that if they are pointed at the top, they serve to saturate an approaching cloud, and to deprive it of its sting before it comes within striking distance. After the city of Pietermaritzburg in Natal had been largely supplied with pointed lightning conductors, under the author's fostering influence, the actual discharge of violent lightning strokes within the area of the town became almost unknown. During several years the only cases that came under the author's notice were the top of two chimney stakes somewhat damaged, and a few lofty blue-gum trees shattered.

On account of the facility with which it could be supplied by ordinary workmen, the author adopted a terminal for the upper end of the conductor in the colony of Natal, which proved very effective and satisfactory. In this arrangement the top of a galvanised iron rope was enclosed in a tube of stout sheet zinc, finished at the summit, for the sake of ornament, by a gilded ball of turned wood, above which the strands of the wire were opened into the form of a sort of brush. Each conductor, in this way, had 42 points of its own, and the augmentation of terminal capacity was secured by the addition of the external zinc tube. The tube also supplied a ready and convenient means of attaching the conductor to chimney stacks, or to other protruding parts of the building.

The especial function and power of points is very pleasingly and completely illustrated by a series of three experiments devised by M. Gavarret, Professor of Natural Philosophy to the Faculty of Medicine at Paris. He first charges the prime conductor of an electrical machine to the highest point of tension that it can contain; he then places near to it an earth-connected rod, furnished with a point directed towards the conductor, and he shows that the tension which can be produced in the conductor diminishes constantly as the angle of the neighbouring point is made less. He next provides a Leyden jar that discharges itself by spark through a given neighbouring point, and unscrewing this point, and replacing it by a crown of points, he shows that thenceforth the same jar will only discharge itself silently and without a spark. He then so arranges the jar that it discharges by sparks below the plane of a neighbouring terminal point, and on fixing lateral points below that plane, the spark-discharges immediately cease.

Perhaps, however, the most telling proof of the beneficial influence of points in relieving the tension of an excited electric is that which is given by a very simple and pretty experiment, most easily performed. If a living man stands upon a stool with glass legs, and is placed in electrical communication with the prime conductor of an electrifying machine at work, with a gold-leaf electrometer on the table three or four yards away from him, and holds in his hand a sewing needle, with one finger pressed over the point, the gold leaves of the electrometer show no manifestation of the electricity in the operator, until he unmasks the needle by withdrawing the finger from its point, when the gold leaves immediately start asunder, under the influence of the stream of electricity which is poured out upon them through the point, even at that distance. Or yet, again, if a large tassel of strips of light tissue paper is made to throw its several strips out into a divergent brush, by electrifying the tassel from a machine, the tassels of the paper collapse together immediately upon unmasking upon them a needle point held in the operator's hand at the distance of two or three feet away. There is one very important result of the employment of terminal points to lightning rods, which should never be lost sight of. A lightning rod with efficient points, and in satisfactory operation, might be grasped by the hand of a living man even when in action, with entire impunity, because, on account of the continued drain set up by the points, the rod can never assume any dangerously high tension. A conductor acting without a point, on the other hand, is in a state of very considerable tension when it effects its first discharge, and if it were grasped in the same way by a hand, would, in all probability, strike through that hand some very inconvenient and possibly painful proportion of the discharge. Conductors that have been acting silently with points have been seen to be struck by sinuous tracks of fire, indicating dangerous discharges of high tension, when they have been disarmed of their points.

Platinum has very generally been recommended for the construction of the terminal points of lightning rods, because it is one of the hardest known metals to melt, and because it is also not easily oxidised. The points are shaped to an angle of from 7 to 10 degrees at the top, and are made a trifle less than 2 inches (5 centimetres by the French) long. In this form they are screwed firmly into the top of a rod of copper, which is then, in its turn, connected with a cable or metallic bar below. The terminal rod is usually made of augmenting size as it descends, and is generally projected from 12 to 20 or 30 feet above the building that is to be protected. Platinum points are specially made for lightning conductors in Paris. They are supplied by Collins, of 118, Rue Montmartre; Beignet, of 96, Rue Montmartre; and Detouche, of 222, Rue St. Martin. The cost of a platinum point at these houses, grafted on brass, and from 50 to 70 centimetres (1·9 to 2·7 inches) long, is from 16 to 22 francs. For better finished work, with larger needles of platinum, grafted upon copper, the cost is from 60 to 200 francs.

M. Francisque Michel considers that the points may be quite as advantageously made of silver alloyed with copper, in the same way that it is when used for coining silver money, that is, containing 165 parts of copper to 835 parts of silver. Such points have the unquestionable recommendation that this alloy possesses a very much higher conducting power than platinum, which has 12 times less conducting power than silver, and 11 times less than copper. Messrs. Sanderson and Proctor construct their points very neatly, by simply twisting the copper tape spirally at the end, after the fashion of an auger, and then filing away the termination of the flat metal into the shape of a sharp angle. The entire terminal is also gilded over the copper to the extent of 8 inches. This kind of point has the very obvious recommendation that it forms a continuous portion of the actual rod, and needs no joining or attachment.

The French electricians strongly recommend, upon the ground of the experiments of Professor Gavarret, that the lightning rod should be terminated by a cluster or a crown of points, instead of by one alone, and M. Callaud has given two sketches in his treatise of forms of terminal points that have been adopted in France, in one of which a circle of ten points radiates at an angle of 45 degrees round the base of the principal terminal, which rises some inches above them; whilst in the other a kind of plume of points feathers out from the base. M. Beignet, of the Rue-Montmartre, exhibits a model of the multiple point which the French electricians most affect. Mr. Francis, of Southampton Street, Strand, constructs a very simple and efficient multiple point of copper. The Hotel de Ville at Brussels, which is a very large building, and which has been furnished with lightning rods upon a very complete scale by Mr. Melsens, a distinguished Belgian electrician, is literally bristling with points. It has 228 points of copper and 36 points of iron in its system.

The lower termination of a lightning conductor requires the exercise of even more care than its upper end, because it is less constantly and less generally under observation, and any shortcoming or mistake in reference to it is fatal to the efficiency of the rest of the arrangements, however judiciously they may have been carried out. A faulty termination of the earth connection is, of all else, the most common and frequent blunder, in relation to lightning conductors, that is made. As that is one of the terminations of the artificially provided conducting track, it must be of enlarged dimensions, as has been already explained. It must be in very intimate communication, not merely with the ground, but with the freely conducting portion of it. If a moist contact can be secured by insertion of the rope or rod into constantly damp soil, the contact need only be large enough to diffuse what is known as the electrolytic action—that is, the chemical disintegration of corrosive metals at moist contact when electric currents are operative—over a fairly extended space. If the contact is made with dry earth, the surfaces must be very large indeed. The drier the material that is involved—unless it be an extended system of continuous metallic substance, such as the underground iron tubes of water and gas supplies in towns, which are among the most efficient ground terminals that can be adopted—the more expanded must be the surfaces of communication and contact.

It is worth while here to make a passing allusion to a few flagrant instances of faulty construction in the establishment of earth contacts of lightning conductors, on account of the strength of the illustration that dwells in such failures. In a well known case of a lighthouse at Genoa, which was injured by lightning, and which was presumed to have been furnished with seemingly efficient protection, it was found that the bottom of the conductor had been plunged into the interior of a stone rain-water cistern, primarily constructed especially to keep out the infiltration of the sea, and therefore well adapted to prevent that moist contact with the mass of the earth which is essential to the object in view. Mr. Preece has drawn attention to a very similar case at Lydney, in North Monmouthshire, where the hollow of an iron gas tube, intended to protect the church, was inserted into the substance of a loose stone that was itself imbedded on dry pavement. One of the most sublime instances of this form, not merely of superfluous, but of actually dangerous care, came under the author's own observation a few years ago, when he found in the case of a church in Norfolk, which was injured by lightning, although the tower was furnished with an apparently sufficient conductor, that the metallic rod was carried through the necks of glass bottles wherever it was attached to the masonry, and that the system of precaution was finally consummated at the base by putting the bottom of the rod into a glass bottle buried in the dry earth. But a few months since, the author undertook to see to the protection of the residence of a friend in the neighbourhood of Kensington Gardens, in which an exceptionally lofty house, even for that aspiring neighbourhood, had to be defended. A sufficient copper rope was brought down from an iron balustrade that surrounded the summit of the roof, but it so chanced that this was left lying at the lower end on the stone pavement of a sunk basement floor before the permanent earth contacts had been established, and that a thunder storm suddenly burst over the neighbourhood while the system of protection was left in that unfinished state. The head of the household, in the absence of his scientific adviser, was, however, equal to the emergency. He had the bottom of the rope carefully coiled away into the interior of a wooden pail, determined, most probably, that if the lightning did come down the rope, it should at any rate be kept in the pail until it could be carried away by some competent hand. In one very instructive instance, a house in Natal, which had been furnished with one of the author's galvanised wire ropes for a conductor, but not under his personal superintendence, was injured by lightning. The house was a low-hipped structure, of one storey. The rope had been brought from the top roof ridge which was of metal, along one of the hip angles, then down a corner post, and buried in the ground. The lightning, however, had perversely preferred to go down an opposite hip, where there was, so far, a metal rod, and had then leaped through the wall, taking some iron sash weights of a window by the way, and shattering the brickwork and doing other damage in its course. The author went down, as soon as he had heard of this accident, to investigate its cause; and the cause was simply this: the lightning conductor had been plunged into a tract of dry sand at the corner of the house. But at the other corner, by which the lightning had effected its own escape to the ground, was an old pool of water that had been filled up with earth, but was still saturated with moisture, and still connected with ramifications of infiltrated soil. In this case the lightning, when it struck the roof of the house, had divided itself between the two routes which were offered to it—the conductor and the dry sand contact of insufficient area, and the wall with its stepping stones of sash weights and its abundant wet contact beneath. The proportion of the discharge which had taken these different routes was determined by the specific resistance of each way, and in the course that involved the leap through the non-conducting wall, the amount which passed was sufficient to produce the destructive disruption which occurred. All competent electrical engineers are now keenly alive to the automatic electrolytic action that is apt to take place in the earth contacts of a lightning conductor, and urge that it is not enough merely to construct an efficient lightning conductor in all its essential particulars, but that the arrangements must be examined from time to time, to make sure that no derangement has taken place. Such examination may readily be effected by making short circuits through the conductor with the wire of a galvanometer, so as to prove by the movements of the needle that the electric path is efficiently clear.

From the instant that an earth contact is established for a lightning conductor, destructive change of the surfaces of contact begins, and, sooner or later, the power of the conductor is materially impaired from this cause. This action, known as the electrolytic disintegration, requires to be constantly watched, beyond all else, and all the more because it proceeds in a region where the conductor is removed from observation by the eye, and it is most fortunate that such watching may be most efficiently and satisfactorily accomplished by so ready and convenient a means as the employment of the galvanometer. M. Wilfred de Fonvielle has indeed proposed that every lightning conductor should have an arrangement of a short circuit wire with the galvanometer attached permanently to it, in a form which he terms *Le Controleur des Paratonnerres*, and which is so designed as to be always ready for the eye of the observer. The author was once very near indeed so furnishing, at his own cost, a proof of the material need of some test and evidence of this character. He had supplied his own residence in the capital of Natal with one of his galvanised iron ropes, with the zinc tube and brush so demonstratively displayed above, as to be a constant object of observation and remark to his compatriots and neighbours. The finial was placed so as to be a sort of advertisement of the enlightened practice of the owner of the house, and a standing reproof to the negligence of those who would not follow so excellent an example. The earth contact was very efficiently made, by carrying the rope along the muddy bottom of one of the streams of constantly running water, that in the old Dutch settlements of South Africa are always found fringing the streets, and during many very severe thunder-storms, the author sat in his easy chair, priding himself on the completeness of his arrangements. He subsequently, however, by mere accident, made the astounding discovery that for a considerable length of time the tail of his lightning rope had not been trailed in the wet mud, but was carefully packed away along a stretch of dry ground, under the shelter of a thick-set hedge, that served effectually to conceal its presence there. On some unhappy occasion, when the author was away, the water-courses had been undergoing cleansing and repair by the civic authorities, and the workmen, finding the metal rope in the mud, had taken considerable pains to pack it away in the drier and cleaner place in which it was ultimately discovered. If any accident from lightning had in the meantime occurred to the house, this case would certainly have lived in the annals of Natal, for a couple of centuries at least, as a remarkable proof of the inefficacy of lightning rods, and the great lightning doctor himself would have been held to have brought down the vengeance of the clouds upon his own ignorance and presumption.

The French electricians have contrived a very excellent expedient for making an efficient earth contact. They construct a stout harrow of galvanised iron, with recurved teeth, connect this carefully with the end of the cable or rod, and then bury it, imbedded in a mass of broken coke, in moist earth. The cable or rod is conducted to a suitable site for this terminal in channels of curved tiles, well filled with broken coke, or even sealed up in leaden tubes, if there are ammoniacal vapours to be encountered by the way. M. Callaud has a still more ingenious and admirable plan of effecting this purpose. He hangs at the bottom of the cable a galvanised iron grapnel, with four upturned and four down-curved teeth, and entangles these within a basket of netted wire, and then packs in this basket with fragments of coke; and the basket, coke, and grapnel are afterwards sunk into a pit or well, or buried deep in moist earth. M. Callaud prefers coke to charcoal, on account of its greater porosity and accessibility to moisture; and he has made some careful experiments to satisfy himself of the size which this earth terminal should have. According to the experiments of M. Pouillet and M. Ed. Becquerel, pure water conducts the electrical force 6,754 million times less freely than copper, and therefore, for free transmission, the earth contact, if effected by pure water, should have 6,754 million times the area of the main conducting cable or rod. This theoretical argument is, however, very materially affected by the fact that the water in the earth contains conducting principles of considerable power, and by other analogous considerations; and an earth contact of 1,000 square metres (1,196 square yards) has been fixed by the best French authorities as sufficient for all practical purposes for a conductor of copper, that is, one centimetre (four-tenths of an inch) square. M. Callaud calculates that in order to accomplish this purpose, his earth-basket must contain one hectolitre (two bushels and eighth-tenths) of broken coke. In order that a lightning rod may perform its work perfectly, it is obvious that there must not be any greater resistance to the passage of the electrical discharge at its earth-outlet, than there is in the rod or main channel of the discharge. Very commonly in badly-arranged lightning rods, it is found that there is ten thousand times more resistance at the outlet into the earth than there is in the main rod of the conductor. When this altogether excellent expedient of M.

Calland's cannot be adopted, a bore 4 or 5 inches in diameter should be sunk 16 or 20 feet into damp soil, into which the cable should be inserted and then the bore should be filled round the cable with broken coke, and the whole be firmly rammed down; or radiating trenches should be cut as deep as possible in the ground, and corresponding branches from the cable be then packed into these with an investment of broken coke. M. Francisque Michel gives an unqualified approval to the attachments of the lower terminal of the cable to iron service-pipes, whether of water or gas, in towns.

In Gay-Lussac's report to the French Academy of Sciences, in 1823, it was held that all large metallic masses contained in any building should be brought into metallic communication with the main system of conductors, and that there was no need whatever for the employment of insulating supports in attaching the lightning rod to the structures that it is intended to defend. These conclusions of Gay-Lussac's have been generally acted upon since his time, and no very marked case has ever occurred to stamp the practice that has been adopted in these particulars as radically wrong. In my own practice, in the colony of Natal, I have almost invariably acted upon them, and no single instance of insufficiency of protection has ever come under my notice in consequence of the arrangement. The point is, however, one upon which there is now some difference of opinion in high quarters. M. Calland, for instance, in his recently printed treatise on the Paratonnerre, insists upon the adoption of insulating supports for the rod, and unconditionally condemns the electrical communication of the rod with the metallic masses contained within the building; and he states in one part of that work, that M. Pouillet has to some extent given in his adhesion to these revolutionary views. M. Francisque Michel, on the other hand, upon a full review of all M. Calland's arguments, maintains the old doctrine that the conductor may safely be attached to the masonry of the building by ordinary staples or holdfasts, or any convenient way, and that insulating supports are of no use whatever, and that all masses of metal contained in a building should, as a general rule, be metallically connected with the main line of the conductor. Professor Melsens, of the Royal Academy of Belgium, one of the highest Belgian authorities, contends, upon experimental grounds, that the well-known laws of derived electrical currents apply with equal force to the transmissions of electrical force of high tension, and that scattered masses of metal in any building should be metalically connected with the conductor by closed circuits constituted by contacts with two distinct points of the rod. This divergence of view among high authorities is of notable import, because it is virtually the only material difference of practice that is encountered in the treatment of this subject by well qualified scientific men, and it may therefore be very readily admitted to be an affair that yet requires a more searching investigation, and further severe question by observation and experiment. In the meantime, it is of some importance that the exact bearing of the doctrine advocated by M. Callaud should be understood.

In illustration of his argument, M. Callaud takes the case of an iron balcony supported in front of the window of a house at some elevation from the ground, and considers the possible result to living men and women contained in this balcony at the time of a severe thunderstorm, accordingly as the balcony is, or is not, electrically connected with an efficient lightning rod. He argues, if the balcony is connected with a lightning rod, a living person standing upon it, or leaning against its rail, is very much more likely to be struck by a discharge of lightning, than if the balcony had no such connection. In the former case the living body is likely to be made a stepping-stone for the lightning on its way to the rod. He holds that in the case of a lightning stroke, the chances are a hundred to one, that a lightning rod is struck in preference to any part of a building, but that if the conductor is faulty in any particular, and scattered metallic masses are connected to it, this is tantamount to attaching the hundred chances of danger to the metallic masses and to living people placed near them. He says, in effect, a satisfactory and perfect lightning rod should be so placed that it efficiently protects every part of the structure it is attached to, and that if it does this, no scattered mass of metal within the building can possibly be struck by a discharge. Therefore connection of the rod with scattered masses of metal is superfluous and useless where the rod is efficient and perfect in itself, and objectionable and dangerous when the rod is not in an efficiently acting condition. And, perhaps, the greatest force of this argument falls upon a fact which is very earnestly pressed by M. Callaud, that a lightning rod is a merely passive piece of mechanism, which does not give visible or palpable signs of its own derangement, like a clock, but which may furnish fatal proof of its imperfection too late, by killing the person who places unmerited and undue trust in its efficiency and excellence. M. Callaud remarks with some force. "Lightning cannot strike a structure that is well protected. If the lightning finds at the side of the Paratonnerre an electrical conductor that is superior to itself, the structure is then inefficiently defended. A Paratonnerre ought to dominate, to cover, to protect, a building in all its parts, and in all its details, or it is better away." The gist of the whole matter, therefore is, take care that your conductor is perfect and efficient in all its parts, and that it is in every sense adequate to the work that it is required to do, whatever may be the size of the building, and then it becomes a matter of small moment whether scattered masses of metal comprised in the building are connected with the rod or are not connected, and whether the rod is connected to the building by insulating or by non-insulating supports. M. Callaud's conclusion, however (and it is the one upon which he states that M. Pouillet has given in his adhesion), is substantially—"Connect any masses of metal with the Paratonnerre that are of necessity removed from the occasional close presence of living people, but on no account ever connect such masses with the Paratonnerre, when they may at any time have living people in their close neighbourhood." Pending further investigation of this very interesting point, there can be no doubt that this distinction is a prudent and a safe one to be adopted in practice, and that it is more prudent and more required in proportion to the insufficiency of the arrangements of the conductor. Conducting masses which are connected with the earth by less readily conducting substances, occasionally give rise to a curious effect, which is technically known as the return shock, and which is altogether a result of inductive action. When a powerfully charged electric comes within a moderate distance of them, an electrical charge of an opposite character is drawn into them by induction, but this secondary charge escapes back towards the earth the instant the inducing tension is removed. The production and character of this return shock, caused by inductive action, admits of very complete illustration by electrical apparatus. An insulated conductor of long cylindrical form, but with its glass supports only half the length of the glass pillar of a prime conductor of an electrical machine, may be placed parallel with the prime conductor, but about an inch away. The secondary conductor is then to be raised to the same height as the prime conductor, by fixing its glass pillar upon the top of a pillar of wood, a fine wire being carried from the metal cylinder to the wood. A wire is then also to be carried from the secondary conductor to the earth, but is to be so arranged, that a small gap may be left in some convenient part of its course. When the prime conductor is charged positively by the machine, the positive electricity of the secondary conductor is inductively driven out through the wire, and the wooden pillar to the earth, and the conductor itself remains negatively charged. But when the working of the machine is stopped, and the prime conductor is deprived of its positive charge by a touch of the finger, the negative charge in the secondary conductor is also set free from its condition of inductively maintained constrain, and positive electricity leaps back from the earth to restore its proper balance and saturation, and as it does so, is seen passing as a spark through the gap in the earth-wire, because that gap affords less resistance to the passage of electricity of tension than the supporting pillar of wood. If a little gun-cotton, or some other suitable inflammable substance is placed in the gap, it is fired by the spark at the instant of the discharge. Professor Tyndall, in his lectures at the Royal Institution, shows the production of this sympathetic inductive discharge in a very magnificent form. He has a flat coil of copper-wire imbedded in a mass of insulating resin, through which he can pass the discharge of the powerful battery of the institution, consisting of fifteen Leyden jars; and he has also a second flat coil similar to the first, which he can place parallel to it and about an eighth of an inch away, the two ends of the second coil being connected with a wire presenting a small gap of continuity. When the discharge of the battery is passed through the first coil, a powerful sympathetic discharge rushes at the same instant through the secondary coil, and makes itself manifest by a bright flash and a loud snap in the gap of the connecting wire. The discharge of an electric cloud in this way not uncommonly produces a number of sympathetic minor discharges from neighbouring bodies. The induced discharge is sometimes quite strong enough to produce mechanical mischief in resisting bodies that lie in its path. The shocks experienced by living people on the instant of a discharge of lightning without fatal results are generally of this character. It was to meet the case of these incidental induced charges, and the consequent "return shocks," that the expedient of connecting scattered masses of metal with the conductor was originally devised. The return shock resulting from a limited inductive disturbance, may be strong enough in some circumstances to cause death by the mere arrest of the vital action of the nerve structures through which it passes, without leaving behind it any trace of mechanical violence, such as is generally produced by the true lightning stroke.

The old practice of protecting buildings from lightning consisted in erecting rods of metal upon wooden frames, near to, but not in actual contact with, the walls of the house. When the author of this article first visited Natal in 1857, the houses in the two principal towns, that were defended at all, had independent conductors of this class, of the rudest possible kind, erected by the side of the one-storeyed houses upon ungainly wooden frames. The conductor was composed of an iron rod, joined in three lengths, and rudely pointed above, and it was made of three different pieces—a comparatively thick one below, and a comparatively thin one at the top. This practice was primarily based upon an investigation which was conceived to demonstrate that all structures lying within a conical space, which had the conductor itself for its height, and a breadth for its base equal to four times the height of the conductor, were safe. This estimate gives a fair approximation to a truth, but it is by no means absolute, and must not be empirically relied upon. It, however, furnishes a very good indication of the way in which the upper termination or terminations of the rod must be arranged. The terminal point should go some considerable distance above the house tops, and then if any projecting parts of the house extend beyond the surface of a line having perhaps a somewhat more acute figure than the one which has been named, other subsidiary points must be reared up from the line of the conductor above such conical slopes. Mr. Preece, in his paper, considers that the lightning conductor should only be held to afford absolute protection within a conical space in which the base is as large again as the height of the line. When, however, the general idea of the limits of this lateral protection is once clearly conceived, it becomes very easy, indeed, to render the arrangements of the upper terminals perfect for any individual case. It is only necessary that all prominent masses of metal shall be connected with the system of metallic communication, and that an additional branch of the system of defence shall be carried out whenever outlying parts of the structure get near to the conical limit of protection. This is virtually what has been done in the case of the Hotel de Ville at Brussels, with its terminal of 264 points.

When Sir William Snow Harris, now some years ago, turned his attention to the protection of ships from lightning, he devised a plan of making the lightning conductor a part of the original design and essential construction of the ship. Now all large and well-contrived vessels are always built with the lightning rod included in their structure. It is almost incredible that up to this time the same course has not been taken with houses. It is hard to understand why lightning conductors should be objects of exceptional luxury, and rain pipes objects of daily need, and the more so when rain pipes themselves can be so easily turned by a little forethought and mechanical ingenuity into lightning conductors of the most efficient character; they only need that their joints shall be made mechanically continuous, that their earth contacts shall be perfected, that all masses of metal, with perhaps the limitation that is contended for by M. Callaud, shall be brought into metallic communication with them, and that metal terminals shall be distributed from them to the roofs above, upon the principle that has been explained. Mr. Preece has thrown out one very excellent suggestion which well deserves further thought; it is to the effect that metal ventilating pipes carried up from the sewers over the roof of the house, may advantageously be made part of the arrangements for protection against lightning. The familiar case of the Monument of London is continually adduced as a proof of the readiness with which the accidental features of a building may be turned to account for this purpose. The metallic emblems of flame at the top of the column are continuously connected with the ground, by means of a very thick balustrade of iron that runs as a hand-rail down the stairs; the structure is 200 feet high, and towers above all neighbouring buildings, and yet it has now stood within three years of two centuries without ever having been injuriously touched by the lightning.

It was conceived, until recently, that St. Paul's Cathedral had been efficiently protected in some similar way by the arrangement of water-pipes and some supplementing of them by metallic rods, added by a Committee of the Royal Society some 120 years ago. Mr. Faulkner, of Manchester, however, found, in a careful examination made subsequently to 1872, that the system had become entirely inefficint for the purpose for which it was intended, by the formation of thick incrustation of rust on the contact surface of the rods, and by the interpolation of blocks of dry granite, some nine inches thick in places, into the actual line of electrical conduction. The entire building has now been most efficiently protected, under the skilful direction of Mr. Faulkner, by carrying eight octagonal half-inch ropes of common wire from the Cross, Ball, and Golden-gallery through the metal-work of the roof of the dome, and through the metal-work and rainfalls of the lower parts of the building to the sewers, where the conducting strands terminate in copper plates pegged into the moist earth. In carrying out this work, every important metallic portion of the building was separately tested by the galvanometer, to make sure that the electrical communication with the earth was virtually and substantially clear. The galvanometer was first made into a circuit with a metallic gas-pipe; and then the circuit was opened out, so that earth was made in one direction through the gas-pipe, and in the other through the metallic portion of the building for the time under examination; and the test was not considered satisfactory until the deflections of the galvanometer were the same under both alternatives. In arranging methodical architectural plans of this kind, it must always be carefully borne in mind that small gas-pipes of easily fusible metal must on no account form part of the connecting lines of conducting circuit. Gas-pipes are most easily fused by a stroke of lightning, and when they are so fused, the gas which escapes from the extemporised orifice is invariably set light to.

One point which was expressly urged by Mr. Preece, and by Captain Douglas Galton, in the discussion of Mr. Preece's paper at the Society of Telegraph Engineers, should be most carefully kept in view in any structural plan matured for the protection of buildings, namely, the including of all fire-places or stoves and soot-blackened chimneys in the system of connected construction. To adopt Mr. Preece's own statement of this need—"It must not be forgotten that a chimney lined with a thick layer of soot, up which a current of heated air and vloumes of smoke are ascending, and terminated by a mass of metal (the grate), is an excellent but dangerous conductor, for it ends in the room, and not in the earth."

Since the first preparation of this paper, two pamphlets by Messrs. Gray and Son, of Limehouse, have come into the hands of the author, which are valuable and interesting, on account of the details which they contain of a considerable series of instances of damage from lightning. Mr. W. J. Gray, of this firm, was orginally concerned with Sir William Snow Harris in perfecting his plan for protecting ships, and obviously possesses a large amount of practical information in regard to accidents that have occurred. Space now only serves to say that the Messrs. Gray endorse the practice of connecting all metallic masses in a structure with the main line of conduction, and especially urge the surrounding of all prominent objects, such as the tops of tall chimneys and church towers, with continuous bands of copper brought down into direct connection with the discharging rod.

The great length to which this paper has already extended itself, alone prevents some allusion being here made to the views of Professor Zenger, of Prague, who advocates the use of circular zone-like or ring-shaped conductors, embracing within their span the objects which are to be defended from injury.

There is no sufficient ground for the popular idea that accidents from lightning are of such rare occurrence, that it is scarcely worth while to incur the trouble and cost which artificial protection involves. The figures of the statistician prove that accidents are very frequent indeed. The Escurial in Spain has been set fire to four times by lightning in less than three centuries. As many as 1,308 persons were ascertained to be killed by lightning in France between 1835 and 1852. Some time ago the mean number of deaths from lightning in each year was marked at 3 in Belgium; 9 in Sweeden; 22 in England; 50 in the United States of America, and 95 in France. M. D'Abbadié records the destruction of 2,000 sheep by a single discharge of lightning. Mr. Preece tells of 897 telegraph instruments injured by lightning in the first six months of 1872, in a staff of 9,475 instruments. Mr. G. J. Symons, one of the Secretaries of the Meteorological Society, has given, as the list of accidents that he had ascertained to have happened during two severe storms in June 1872, 10 deaths and 15 cases of injury to human beings: 60 houses struck and 15 burned down; and 23 horses or cattle and 99 sheep killed. It need scarcely be said that many accidents also occur every year from lightning, over and above those which get publicly spoken of or placed on record. In large towns, damage to property is more frequent than destruction of human life, but in the open country, destruction of life is the more frequent occurrence. In the face of figures like these, and of the fact of the slowness of man to avail himself of the ready defence which science places at his command, unfortunate humanity certainly stands very much in need of the consolation which the physiologist affords, when he tells us that all danger from lightning is passed when the flash of the electrical discharge is seen, and when he further states that when men are killed by lightning, they are dead before they have time to know anything about the fact, or indeed to be conscious of the fatal blow—a conclusion, by the way, which is strikingly corroborated by an unintentional experience of Professor Tyndall's, who upon one occasion passed the full charge of the powerful Leyden jar battery of the Royal Institution, by accident, through him, and was perfectly unconscious of any shock. It is something, at any rate, to have this comfortable assurance when the sense of neglected opportunity comes over the mind in an exposed situation, and in an unprotected house during a severe thunder-storm. But it is humbly submitted, as an appropriate last word of this paper, that to men of well-regulated minds, a good lightning conductor may, in such emergency, be found to be an even greater satisfaction and comfort.

R. J. M.

No. CCXLI.

SUGAR-CANE CRUSHING MILL.

[*Vide* Plate XLII.]

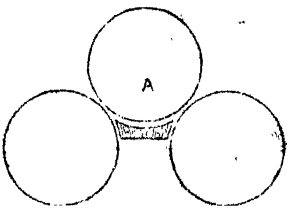
Designed and constructed by LIEUT. J. CLIBBORN, B.S.C., *Assist. Engineer, Northern Division, Ganges Canal.*

EVERY Irrigation Officer, when riding through his district during the sugar-cane crushing season, must have noticed the difficulty which the cultivators find in providing bullock power to work their *kolus*; and the slovenly manner in which they allow the juice, when expressed, to get mixed with pieces of cane and other foreign matter, which are rarely removed before boiling; and he must have felt a wish to utilize the many small falls in our distributaries near to sugar cultivation. It is evidently more economical and certainly more agreeable to the cultivator to place the means of crushing and boiling his sugar in the midst of his fields and near his village, rather than at some large fall on the canal, to which he would have to carry his cane a considerable distance in most cases.

The water-wheel and mill just erected at the Bhaisáni Falls, right main rajbaha, Northern Division, Ganges Canal, is intended to supply the want alluded to above; and for that reason, has been designed and constructed in the simplest and cheapest manner possible, being almost entirely made of wood, of which a great part was obtained from the canal plantations. It was built by a country mistri, and can be kept in order by the ordinary village carpenter, whom the cultivator employs to look after his kolu during the season. It must be remembered, also, that with a few simple additions, the water-wheel is available for grinding corn, lime, &c., and, indeed, being a cheap source of power in the heart of the villages, might lead to many useful manufactures being introduced.

The simplicity of the mill consists mainly in the fact that the shaft A of the water-wheel, prolonged, is also the upper roll B, which does away with the necessity for complicated methods of communicating power. The framing C is also simple, being made triangular, and the adjustments being effected by wedges D. The Indian cane is not, I believe, so stiff in structure as that grown in the West Indies, and the ordinary method (*see Fig.* 1 in margin) of causing the cane, after passing through the first pair of rollers, to turn up and go through the second pair, would not answer. A fluted roll E, made of sissú wood, was therefore substituted. It is caused to revolve by means of the kikar cogs driven into the main shaft at F, and answers perfectly.

Fig. 1.



Motion in the required direction is communicated to the two lower rollers G, G, from the upper shaft, by the cog-wheels H, H, which are made of wood instead of cast-iron. Since, if a cog breaks it can quickly be replaced, and the motion is smoother; moreover cast-iron spur-gear of that size, would cost half the total price of the whole mill.

The cane is put into the rollers at I, being simply laid on the board I, touching the rollers which will draw it between them. It then passes forward and through the second pair, the dry megass passing over the board J, and falling on the ground. The expressed juice falls between the rollers and through the sheet of perforated zinc K underneath, (which catches all the broken bits of cane, &c.,) on to the sheet iron L, and then into the trough M, from which it can flow into the boiling pans at once, or can be further filtered if desired. The grooves ½ inch deep, which are shown at the edges of the rolls, are to prevent the juice flowing out at the bearings.

As the mill is not always working, it is necessary to make arrangements for passing off the supply of water when not required. In the case of the Bhaisáni Fall, this was particularly difficult, as the right Muhammadpur rajbaha supplies the right main immediately below the wheel. I have not, however, shown this in the drawing, as it would render it unnecessarily complicated.

I have supposed the case of a rajbaha with 2 feet 6 inches depth of water, and a contracted sill at the fall, which maintains the normal velocity. For contracted sill, I substitute a raised sill at the required height above the bed. This raised sill is really a sluice gate N, which when lifted, allows the supply to flow away below the trough.

Fig. 2.

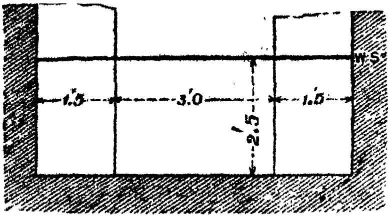
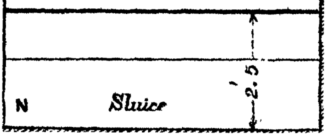


Fig. 3.



The bottom of the supply trough is level with the top of this raised sill, and therefore the trough receives the whole supply of the rajbaha, as long as the raised sill is standing.

This sluice is shown in the plan as N, and a second sluice O is also put in to enable the supply to be suddenly shut off from the wheel in case of an accident. When sluice O is let down, it will be found that the supply in the rajbaha will not rise too fast to allow of the sluice N being taken out.

The sluice can be worked with a screw and wheel, (as used at Bhaisáni) rack and pinion, or by hand, or planks can be put in.

In cases where a side escape is possible, it is of course to be preferred.

Description.

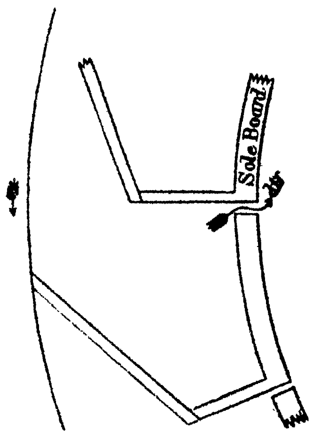
The main shaft is made of sissú wood 18 inches diameter, hexagonal, where it forms the water-wheel shaft.

This hexagonal portion is slightly tapered to one end and reduced in thickness at the middle, in order to allow it to pass into the spokes of the wheel, where it is wedged up, and small angle pieces (*a*) are bolted on to retain it in place. The arrangement of the spokes *b* is shown in *Fig.* 1; they are sál scantling 8″ × 3″, and are quite stiff enough without any cross bracing.

The shrouding P, which is 18 inches deep, is made of $1\frac{1}{2}$ inches deodar planking, and is fastened on the spokes *b*. It is fixed underneath the first pair, let into the second, and over the third pair, in such a manner as to remain in the same plane.

The buckets Q, of 1 inch deodar planks, are let into ½-inch deep grooves in the shrouding P, and the whole wheel is kept together by twelve ½-inch bolts C, passing through the ends of the spokes. The sole-boards R, also 1 inch deodar, are nailed on to the shrouding and buckets, in such a manner as to leave a ½ inch slit at the top of each bucket for ventilation. *See Fig.* 4.

Fig. 4.



The main shaft is supported on kikar bearing pieces S, S, which are bolted down to a framing T, made of shisham or bahera, and fixed firmly in the masonry of the falls.

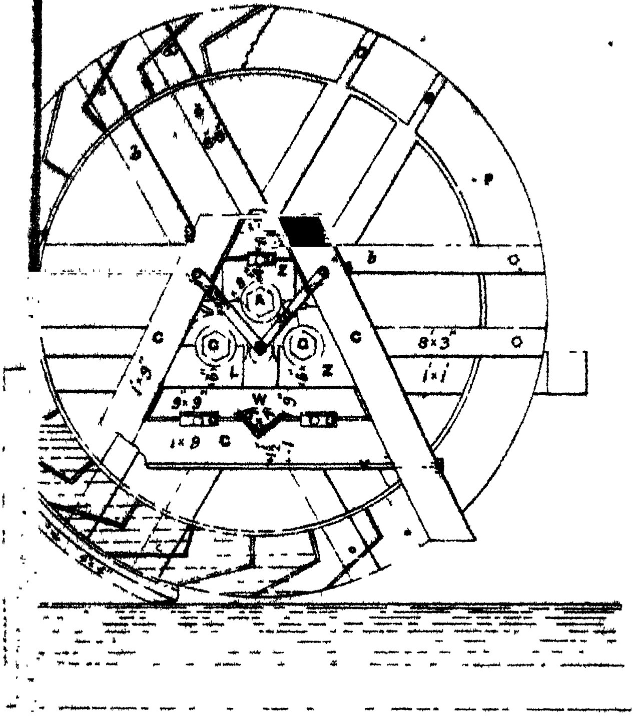
The framing C of the mill is made of sál wood securely morticed, and held together by 1½ inch bolts V, V. The lower portion is imbedded in masonry to prevent movement. The bearing blocks of the lower roll G, G, are supported on a bar W, beneath which are two wedges D, D; by means of them and the wedge above the upper roll, adjustment required can be affected. The wedges have bolts through them. *See Figs.* 2, 3, which, when screwed up, prevent any chance of slipping.

The bearing blocks Z of the forward lower roll are carried over as well as below the bearings, in order to prevent the roll rising. All these bearing blocks are tongued into the frame to prevent lateral movement, and either of the two lower rolls can be removed from the frame by easing down the wedges.

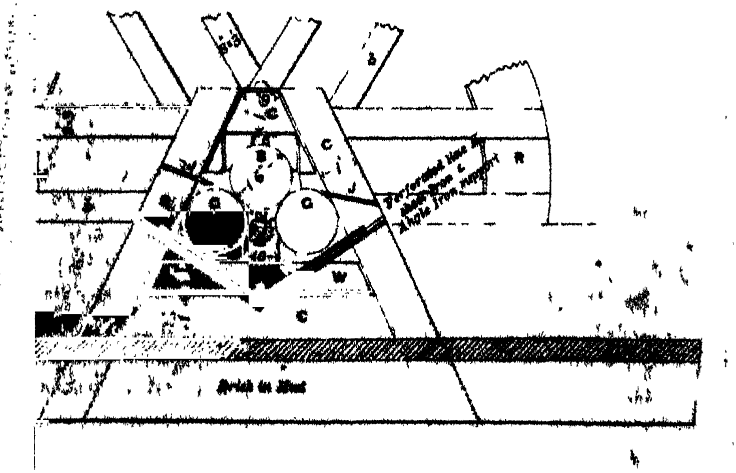
The cog-wheels are made of a block of sissú with kikar teeth dovetailed in, and then two iron rings are shrunk on at each end. They have slightly tapered hexagonal holes cut in the bosses, which fit on to the ends of the rollers. It is better not to drive these quite home in the first instance, so as to allow of their being tightened up occasionally.

The sheets of iron to catch and carry the expressed juice to the delivery-trough are supported on small angle irons screwed to the frame, so as to allow of their being drawn out to be cleaned, &c. For the sake of portability, they are made of light sheet-iron on a wooden frame. On top of them are laid the sheets of perforated zinc, which are kept from

ELEVATION AND SECTION



SECTION THROUGH ROLLERS
WEDGES REMOVED.



touching by a small ledge 1 inch high. A little black lead applied occasionally is all that is required for lubrication. The bearing should be kept dry, and the surface speed of rollers ought not to be more than 20 feet per minute, or else all the juice is not expressed from the cane.

It would be a great improvement to shrink iron collars 6 inches wide and $\frac{1}{2}$ inch thick, on the water-wheel bearings, which would prevent any wear.

It would also be advantageous to cover the rolls with $\frac{1}{8}$-inch or $\frac{1}{16}$-inch sheet iron.* These improvements would add very little to the cost of the mill, certainly not Rs. 50.

If any difficulty should be found in procuring sissú wood, of sufficient scantling to make the main shaft, it could be built up of a core of sál wood one foot diameter, and thickened at the places required, by the adtion of strips of kikar or sissú. Built up shafts like this are in common use in many parts of the world, and withstand the effects of climate better than solid work. This of course would necessitate the iron sheeting. With a supply of 14 cubic feet per second, and a fall of 4·25 from surface to surface, this mill will crush one maund of cane in four minutes.

This outturn, however, depends entirely on the fall available, as the wheel and mill are quite strong enough to crush twice that amount with a sufficiently high head of water.

I append a list showing the woods of which the principal parts are made. This of course can be altered if considered necessary, but I think those used are the most suitable.

Mill framing,	sál.	Cog-wheel bosses,	sissú.
Sluice gates,	"	Cogs,	kikar.
Wheel spokes,	"	Bearing blocks,	"
Framing to support,	"	Wedges,	"
Wheel, any wood not likely to be affected by dry rot.		Shrouding,	deodar.
		Sole board,	"
Shaft and roll,	sissú.	Buckets,	

Memorandum by Executive Engineer.

The wheel, which was made by Mr. Clibborn as an experiment, was set up at the Bhaisáni Fall on the right main rajbaha. The discharge being about 14 cubic feet a second, and the fall 4·25 cubic feet, the nominal horse-power used is about 6·2. With this nominal power, the mill crushed one maund of cane in four minutes.

* A better plan found necessary after last year's working, is to cover the rollers with kikar wood on end, 3 inches thick, dove-tailed into the rollers—this appears to wear very well.

This year we cannot judge of the extent to which the sugar-growers will be likely to avail themselves of it; because they had made their arrangements for the season's crushing before the mill commenced to work. From the following calculations by Mr. Clibborn, it appears that a great saving would be effected by its use.

The mill crushes 1 maund of cane in 4 minutes.

1 „ of juice in 8 „

Now 200 maunds of juice to the bígha is a very fair average return. I should say much above the average.

Therefore 200 maunds (= 1 bígha) in 1,600 minutes = 26 hours, or including stoppages, &c., ... = 30 hours in a working season of 3 months, the mill would crush therefore $\frac{90 \times 24}{30}$ = 72 bíghas.

According to the following statement, which is the average of results of separate enquiries made by the Deputy Magistrate, Ziladar, and Sub-Overseers, which agree very fairly, and with which is contrasted the estimate of Mr. Butt, C.S., in the Revenue Reporter, it appears that the cost to the cultivator of crushing the produce of one bígha is Rs. 12-11-0. As, however, this amount is never actually disbursed in cash, and as we wish to induce the cultivators to use this mill, we should of course fix a much smaller rate than this.

Estimate of expenditure incurred in crushing one bigha of sugar-cane by native "kolu."

	Nazar Ali, Sub-Overseer.			Zen-ud-din Deputy Magistrate			Abdul Karim, Ziladar.			Mr. Butt in Revenue Reporter.		
	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.			
Cutting sugar-cane in short pieces	0	4	0	0	14	0	0	10	6	Mr. Butt does not give this item separately, but he agrees so closely in the total that I could deduce it.		
Pedia and Muthia who put cane into press, ...	1	11	0	2	2	0	2	1	0			
Miscellaneous repairs of "kolu,"	1	0	0	0	12	6	1	4	0			
Price of láth, ...	3	0	0	3	0	0	0	15	0			
Hire of bullocks, ...	6	0	0	6	0	0	6	0	0	11	4	0
Hire of kolu and pans, ...	0	11	0	0	11	0	1	2	0	1	14	6
Total, ..	12	10	0	13	7	6	12	0	0	13	2	6

Average = Rs. 12-11-0.

The earnings of the mill at the rate of kolu cost = 72 × Rs. 12-11-0 = 913 in one season.

One point must be borne in mind, which is, that the cost of construction would not be increased if a greater fall of water was available, but the outturn would be more. In fact the rollers and framing, for the sake of simplicity, have been made quite strong enough for water, giving twice the power now exerted at Bhaisáni.

This mill and wheel are of the most simple construction, and could be kept in repair by the ordinary village workmen.

Measurements.

Description.	No	Length.	Breadth.	Depth.	Contents.	Total.
Deodar wood.						
Shrouding,...	2	50·0	...	0·16	16·0	
Backing, ...	1	27·0	5·5	0·1	14·8	
Buckets, ...	24	2·0	5·25	0·1	25·2	
Breast-boards, ...	1	10·0	6·0	0·16	9·6	
Total, deodar wood, ...	...	...	...	...	...	65·6
Sál wood.						
Spokes, ...	12	12·0	0·66	0·25	23·76	
Frame, ...	4	8·0	1·00	0·75	24·00	
"	2	6·0	1·00	0·75	9·00	
"	2	5·0	0·75	0·75	5·62	
"	1	5·0	1·00	1·00	5·00	
Total, sál wood, ...	...	...	...	...	...	67·38
Shisham wood.						
Shaft, ...	1	14·0	1·8	...	25·2	
Rollers, ...	2	5·0	1·8	...	18·0	
Fluted rollers, ...	1	6·0	0·5	...	3·0	
Cog-wheels, ...	3	1·0	1·8	...	5·4	
Framing under kikar bearings, ...	2	12·0	1·0	1·0	24·0	
Total, shisham wood, ...	...	...	...	...	...	75·6
Kikar wood.						
Bearings, ...	2	6·0	0·75	1·0	9·0	
"	4	3·0	0·75	1·0	9·0	
"	2	2·0	0·75	1·0	3·0	
"	5	...	...	...	5·0	
Total, kikar wood,... ...	...	...	...	...	...	26·0
Ironwork.						
Bolts, &c.,...	½"	72	r. ft.	...	47 lbs.	
"	¾"	24	"	...	36 "	
"	1"	16	"	...	64 "	Mds.
"	1½"	22	"	...	136 "	283/80 = 3·5
Trough, &c., ...	...	...	...	...	...	1·0
Total, Ironwork, ...	...	...	...	...	...	4·5

Abstract.

Items.	Quantity.	Rates. Rs. A. P.	Rates. Per.	Contents.	Total.
Deodar wood, ... c. ft. ...	70	@ 1 0 0	C. ft.	70	
Sál wood, ... " ...	70	" 2 0 0	"	140	
Shisham wood,... ... " ..	76	" 1 8 0	"	144	
Kikar wood, ... " ...	25	" 1 8 0	"	38	
Iron-work, ... Mds., ...	4·5	" 15 0 0	Mds.	67	
Labour, ...	...	...	...	250	
Total, ...	...	...	...	...	679
Contingencies, ...					Nil.
Grand Total, ...					679

Note by Major C. S. Moncrieff, R.E., *Supdg. Engineer*, 1*st Circle, Irrigation Works, N. W. Provinces.*

When I saw the mill working near the village of Bhaisáni, zila Muzaffarnagar, on the 20th January last, nothing could have been more satisfactory. I saw two maunds of cane crushed in 8¼ minutes, with a yield of 37 seers. This is just as good a result as has been obtained at Bhola with far greater outlay and trouble.

The great point of Lieutenant Clibborn's mill is the fact of its being built of wood, and its great simplicity. As Captain Tickell says it started too late in the season to enable us to judge how far it would be popular, but I have little doubt on this subject. The fame of the Bhola mill has spread up and down the canal, and the Ját zemindars will not be slow in discerning a method of pressing their sugar-cane without the ruinous wear and tear at present occasioned among their cattle.

Note by Lieut.-Col. H. A. Brownlow, R.E.

This mill shows an appreciation of the real wants of the natives, which is especially commendable. It can be made by any good "mistri," of materials easily procurable, and can be repaired by a village carpenter.

Although, I think Captain Tickell's estimate of its performances rather sanguine, yet the saving of labour effected by this mill is so great, that there is ample margin left for reduction.

An acre of sugar-cane may be taken as yielding 400 maunds of cane, from which one-tenth, or 40 maunds, will be amount of "gúr" obtainable. The mill crushed two maunds of cane in 8¼ minutes in the presence of the Superintending Engineer, but as it is not likely to be worked at all times with the same diligence as when on inspection, 10 maunds in the hour, or 180 maunds in a working day of 18 hours, is about as much as we can fairly hope to obtain from it, on an average.

At this rate of working, it would crush 400 maunds in 2¼ working days, and could dispose of the produce of about 40 acres during the cane-crushing season of three months.

The cost of the mill is estimated at Rs. 680, say Rs. 700. The expenses of working it would probably be as follows:—

Depreciation at 10 per cent., ...	Rs.	70
Interest at 7 per cent., ...	"	50
Water-power, ...	"	60
Repairs during working season—		
Materials, ...	"	25
Labour, ...	"	5
Establishment employed for three months, ...	"	30
Hire of boiling pans, &c., ...	"	45
Sundries, ...	"	15
Total, ...	Rs.	300

The cost of crushing a bígha of cane under present arrangements is estimated by Captain Tickell to average Rs. 12·75 A canal bígha being ⅝ of an acre, the produce of cane on it will be ⅝ × 400 maunds = 250 maunds, and the resulting amount of "gúr" will be one-tenth, or 25 maunds. Therefore Rs. $\frac{12 \cdot 75}{25}$ or eight annas per maund, is present cost of turning out the crude "gúr."

Supposing a contractor to lease our mill for Rs. 180 for the season, he would pay us Rs. 60 for our water-power, provide for renewal of the mill in 10 years, and pay 7 per cent. on original outlay. He would probably incur about Rs. 120 expenditure on other accounts; and supposing him to charge six annas per maund of "gúr" turned out, he would clear (40 acres × 40 maunds × Rs. ⅜—Rs. 300) = Rs. 300 as his share of the profits.

No. CCXLII.

DEFENCE AND RIVER-TRAINING WORKS OF THE INDUS AT LUNDI.

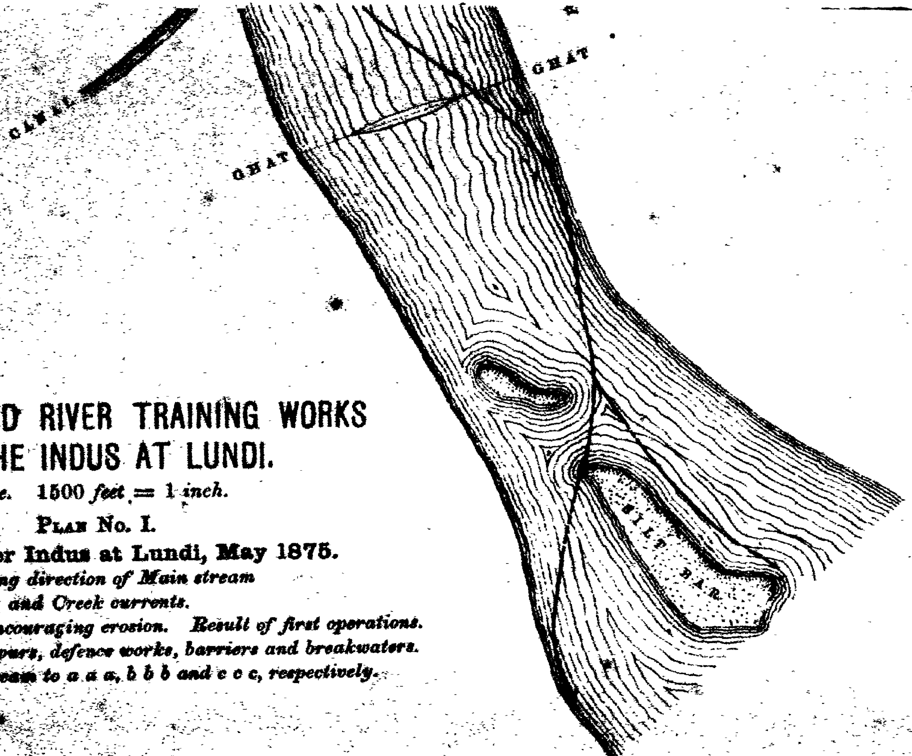
[*Vide* Plates XLIII. and XLIV].

By Griffin W. Vyse, Esq., *Assoc. Inst. C.E., M.R.A.S., F.R.A.I., F.G.S., F.R.G.S., &c., Exec. Engineer, Irrigation Branch, Punjab.*

This paper will describe briefly certain measures which were adopted during the Inundation Season of 1875, to protect the west bank of the Indus near Lundi, when very severe erosion set in some distance above and below the ghât, and threatened certain bunds and canals. Various experiments were tried, one after the other, until we succeeded in baffling the terrific encroachment, and turned the main current from attacking a weak and dangerous point. As these works were carried out on the most economical principles, and at the same time highly successful, they may be worthy of recording, and prove useful to Engineers engaged in training these erratic Punjab rivers. An accurate survey of the river was made, for several miles above the works, and the whole carefully studied and gone over in a boat, all contortions, bends, angles, nature of banks, and soundings were shown. Velocities were also taken wherever practicable. The erosion lines were daily observed and recorded, the direction of each current and stream of the main river or creeks was shown, and all alterations of currents noted as they occurred. The erosion went by fits and starts, when the river remained the same level. It may be laid down as a general principle, that where the erosion is most actively at work, there the main volume of the river is, the deepest soundings will be observed, the scour will be greater than elsewhere, and the velocity more rapid. The most active erosions take place after a freshet or flood, when the river is falling. They seldom go on when a river is rising, and cease altogether when the floods have reached their maximum height.

At A we commenced operations: a floating breakwater 2,000 feet long was fixed from this point, and held by strong auxiliary 8-inch cables, at distances of 50 feet to 100 feet apart, to anchors of *tranjars* of 20 maunds each. This breakwater was twice carried away, simply from undermining. It was subsequently considerably strengthened, and double supports were thrown out from the flanks. Additions were made to it, until by the end of May, it measured something over 6,000 feet in length. The fascines which composed the floating breakwater, were made on the high bank, and then rolled into place. They measured 25 feet to 50 feet in length, and 8 feet to 12 feet in diameter, they were corded and interlaced throughout. Ample jungle, (*i.e.*, brushwood) was at hand for all our wants. A platform was subsequently formed, which with the silt and dèbris of the river, made the floating breakwater an irresistible barrier, against any action of the river. At J on the east bank, a direction spur No. 5, was thrown out to meet the current, to encourage the erosion to eat into the soft bank to C; when this was effected, the spur No. 5, at J was removed. The action of the main stream along this reach became very extraordinary, and whirlpools of terrific force played about in the concaves of the main current. The smaller whirlpool within the bay was checked on the spur No. 3, being thrown out at an angle of 45° with the current, and the main line No. 1 increased. The obliquity of the thread of the stream, impelled and repelled, became too great for the concavity formed by the erosion at C, and from the acute angle *a'*, *a,' a'*, it formed on the river rising a foot, a less sharp curve C, *b'*, *b'*, *b'*. This curve, however, was unnatural, and scouring out of the bed above J, showed us what the river intended to do. The spur No. 3 was removed, and one placed at No. 4. The scour increased from the east to the west bank, and as it advanced, it carried the main stream with it. The river rose suddenly 1·5 feet, and assumed the more natural curve *c'*, *c'*, *c'*, *c'*. At F, the stream was eroding into the sandy shore, when a flood forced the pent up water to take the more direct course, and from a small creek, a channel of considerable size (discharge 12,000 cubic feet per second) was formed at F, which, however, silted up towards the end of the season. Silt bars GH and DE, *Plate* XLIV., showed themselves after the river fell, and to prevent the river from pursuing a more westerly direction, barriers of 2,000 feet each were run up, on the silt bar DE, and floating break-waters hung from these. The consequence was that the velocity of the river was so far decreased here, that on it rising to its maximum height over the bar DE, silt and other *dèbris* was collected, until an island of nearly a mile in length was formed. These spurs, and those lower down, were now considerably increased, and strong supports and barriers placed, with due regard to the direction of the flood current, as shown on *Plate* XLIV. The total cost of these defence works was something under Rs. 4,000.

The result of this working proved, that however erratic and treacherous the Indus is, it obeys certain laws. That the concave and convex arcs formed by the main stream, altered very considerably before, and after and during a flood. The sharpest curve *known* (in the impelled and repelled angle) is 15°, but the velocity will not exceed 1·78 feet per second, and this angle will become greater, in due ratio, as the velocity increases. The greater the velocity, the less the contortions. The Indus in flood being 1·00 in length, the winter channel will be 1·657, or 0·657 longer. This is the average, over the reach, under notice, and the average fall per mile, is 0·87 of a foot. (I confine these remarks to the sandy nature of the bed and banks of the Indus). Therefore, as in *Plate* XLIII., when the current is as J, A, B, and the stream can be forced or encouraged as in this case to the point C, which formed an angle of 88°, the velocity at the time being 2·45 feet per second, and the impelled and repelled angle at AB, being 30°, the current was compelled to take a different course on the velocity increasing to 3·18 feet per second, as shown by the alignment of the current *b′*, *b′*, *b′*. AB being held, and the bay not increasing in any way, it soon silted up. The angle at C became greater each day as the velocity increased, until it formed the easy curve from concave to convex as in *Plate* XLIV., when 12 feet per second was recorded. The Indus was calculated at 52,000 cubic feet per second discharge in May, and by June, a month later, when we had straightened the river and made all safe, the discharge was calculated at about 3,37,000 cubic feet per second. In *Plate* XLIII., the fall from C to A was nearly a foot in May; and in June, the fall from D to B was not more, with a greater discharge. Those great mas-



FENCE AND RIVER TRAINING WORKS OF THE INDUS AT LUNDI.

Scale. 1500 *feet* = 1 *inch.*

PLAN No. I.

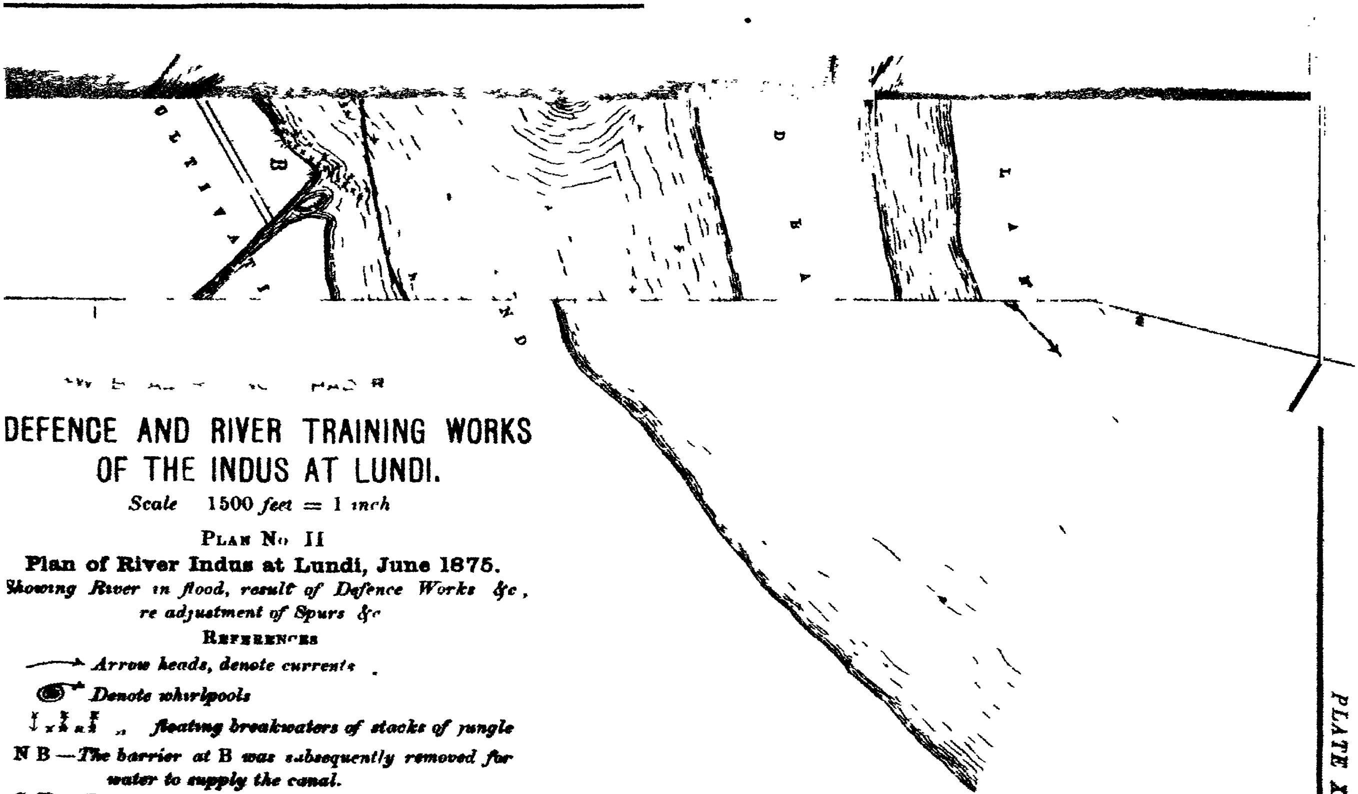
Ian of River Indus at Lundi, May 1875.

Showing direction of Main stream and Creek currents.

checking or encouraging erosion. Result of first operations.

f scouring. Spurs, defence works, barriers and breakwaters.

ge of main stream to a a a, b b b and c c c, respectively.



DEFENCE AND RIVER TRAINING WORKS OF THE INDUS AT LUNDI.

Scale 1500 *feet* = 1 *inch*

PLAN No II

Plan of River Indus at Lundi, June 1875.

Showing River in flood, result of Defence Works &c, re adjustment of Spurs &c

REFERENCES

Arrow heads, denote currents.

Denote whirlpools

" *floating breakwaters of stacks of jungle*

N B —*The barrier at B was subsequently removed for water to supply the canal.*

G. H.—*Recent formations.*

ters in hydraulics, Frisi and Guglielmini, in speaking of rivers acting thus, say as to their remaining permanent. "If they carry substances homo-"geneous, such as sands: if there be sufficient *fall* and *strength* (of velo-"city to carry the silt and sands) on to their utmost limits; and further "if the whole (alignment) can be enclosed in the plane of the country, "the success of the undertaking will be sure." Showing that once the Indus is tolerably straight, it could be kept so, by means of dredging, and defence and training works, such as I have described.*

G. W. V.

* *See* "Professional Papers on Indian Engineering," No. CXXIX., on "River-Training of the Indus," by the same author, for subsequent season's working, for the success of which, Messrs. Ivens and Vyse received the thanks of the Joint Secretary to Government, Punjab, P. W. D., Irrigation Branch.

No. CCXLIII.

KANKAR LIMES AND CEMENTS, BARI DOAB CANAL.

[*Vide* Plate XLV.]

(Second Paper).

By A. Nielly, Esq., *Assist. Engineer.*

Dated Gurdaspur, 20th April, 1877.

The knowledge of the quantity of water which, mixed with cements or limes, imparts to them the greatest tenacity, being a very desirable datum not to be found in books, experiments have been made which have given the following results:—

Table I.

Materials used	Percentage of Water employed	Age of Specimens	Mean Tensile Strength	No. of Specimens broken
1. Kankar from Batala, no more cleaned than the kankar used for road-making generally is; burnt with wood; cement ground and sifted through sieve 1,600 meshes to the inch, ..	25 per cent. of weight of cement,	7 days	11 lbs. per square inch	4
		1 month	40 " "	5
		20 months	114 " "	6
2. Materials as above, ..	30 per cent., &c.,	7 days	9 " "	4
		1 month	52 " "	4
		20 months	137 " "	4
3. Materials as above, ..	35 per cent., &c.,	7 days	10 " "	4
		1 month	50 " "	4
		20 months	129 " "	4
4. Materials as above, with this difference that the kankar was thoroughly washed,	25 per cent., &c.	7 days	9 " "	4
		1 month	46 " "	4
		20 months	27 " "	5

From the preceding table it may be inferred—

1st. That if we neglect the results obtained after seven days, the other results show that the best proportion of water lies between 30 and 35 per cent., so if we adopt 33 per cent., or one-third of the weight of the cement as the best, we shall have a fraction easy to remember, and which will be near enough the very best proportion of water. The greater porosity and consequently the lower strength of the specimens with 35 per cent. water supports the above inference.

2nd. That when the kankar is washed as in results No. 4, the cement deteriorates after some time. This was a very unexpected result, still it must be inferred from it that much cleaning of the clay which surrounds the kankar is unadvisable.

The same kind of experiments were repeated on stone-lime and súrkhí, and the results were—

TABLE II.

Materials used	Percentage of Water employed	Age of Specimens	Mean Tensile Strength	No. of Specimens broken
1. One—by measure of fresh stone lime from Dhoungoo hills; two—fresh súrkhí made with under-burnt stock bricks which had been in stock for four years. Materials ground and sifted through sieve 1,600 meshes to the square inch, ..	25 per cent. of weight of lime & súrkhí mixed, ..	7 days 1 month 20 months	29 lbs. per square inch, 45 " " 11 " "	4 4 6
2. Materials as above, ..	30 per cent., &c.,	7 days 1 month 20 months	20 " " 52 " " All specimens destroyed.	4 4
3. Materials as above, ..	35 per cent., &c.,	7 days 1 month 20 months	24 lbs. per square inch, 51 " " All specimens destroyed.	4 4
4. Materials as above, ..	40 per cent., &c.,	7 days 1 month 20 months	23 lbs. per square inch, 45 " " All specimens destroyed.	4 4

The examination of the tensile strengths after one month, given in the preceding table, suggests also that the tenacity declines after about 33 per cent. water; but leaving aside for a moment the question of the best proportion of water, it shows a most important fact that the first specimens, the only ones which could be preserved, had almost completely lost their strength after 20 months. This fact corroborates not only the warnings of M. Dejoux against stone-lime and súrkhí, but also the experience acquired by the undersigned, who has often remarked that every kind of specimens made with these materials, lost their tensile strength in atmosphere without losing their good appearance externally.

As the question of stone-lime and under-burnt súrkhí is one which cannot be decided without most weighty evidence, because súrkhí made with under-burnt bricks is, when mixed with lime, the cementing material believed in by many throughout India, numerous specimens have been made again, which will be submitted to higher authority, and tried every year and in every way.

In the meantime, Engineers who are going to use the mixture for important works not in water, are warned that they run some risk. "Not in water" is said advisedly, because there is no evidence yet that the weakening does not begin with the drying of specimens exposed to air; but although the writer has no such evidence, it is his opinion that the weakening takes place in water as well as out of it, because such loss of tenacity is due to the chemical action of salts present, either in the clay which was burnt for súrkhí, or in the water which was employed for making the masonry, or in the water in which the masonry is laid.

This subject will be taken up again further on, but it may be as well to state now that the specimens mentioned in Table II. were made and treated in exactly the same manner as the specimens of kankar cement in Table I., and had been kept like them in the same place in the godown devoted to experiments, where they had been out of water for about seven or eight months.

Further experiments on the best proportion of water were made with stone-lime and súrkhí, both about four years old, and they gave the following results :—

TABLE III.

Materials used	Percentage of Water employed	Age of Specimens	Mean Tensile Strength	No. of Specimens broken
1. One, by measure stone-lime to one surkhi, both from old stock, cleaned, ground, and sifted through sieve, 1,600 meshes to the square inch, ..	35 per cent. of weight of lime and súrkhí mixed,	1 month 19 months	23 lbs. per square inch, 27 " "	4 5
2. Materials as above, ..	45 per cent., &c.,	1 month 19 months	23 " " 19 " "	4 2
3. Materials as above, ..	50 per cent., &c.,	1 month 19 months	14 " " 12 " "	4 1

More water than in the preceding experiments was used with these materials, on account of the age of the lime. Owing to the weakness of the specimens, very few could be preserved for experiments, and the numbers which remained are not sufficient to establish means. No inference will therefore be drawn from this table, except that the deterioration of the specimens seemed to be less active than in the case of specimens from Table II. This is due to a much smaller proportion of píla súrkhí having been adopted.

The last facts to be adduced in favour of the so-called "dry process" of manufacturing concrete, are the results contained in the following table:—

TABLE IV.

Materials used	Percentage of Water employed	Age of Specimens	Mean Tensile Strength	No. of Specimens broken
1. Kankar from Batala burnt with upla, cement ground and sifted through sieve 3,600 meshes to the inch,	25 per cent. of weight of cement,	1 month 6 months 1 year	61 lbs. per square inch, 75 " " 82 " "	5 5 5
2. Materials as above, the specimens were made with the cement used for making the blocks at Dharwal, ..	30 per cent., &c.,	2 years	218 " "	10
3. Materials as above,—specimens made with cement used for making blocks at Kullair, ..	30 per cent., &c.,	2 "	265 " "	5

The results two and three given above, show tensile strengths greatly superior to that given for Roman Cement in Molesworth's Pocket Book, 17th Edition, namely 185 lbs. per square inch. This, it is hoped, will convince every one that in point of tenacity, the classification of the so-called kankar lime from Batala among the Roman Cements was not misleading. (*See* Mr. Higham's report, paragraphs 4 and 12 of No. CCXXV., 2nd Series).

In conclusion of the subject which is the best proportion of water for cements, it will be said that Colonel H. A. Brownlow, R.E., in his report No. 21001, dated 7th August, 1875, to the Joint Secretary to Punjab Government, Irrigation Branch, reviewing Mr. Higham's summary of the writer's reports, states, paragraph 4, that " the relative tenacities of concrete prepared under the wet and dry processes have yet to be tested, and any marked superiority in this respect would weigh very heavily in favour of the stronger. As the quantity of water used for the dry process is, as stated in previous reports, from 25 to 35 per cent. according to the dryness of atmosphere, whereas the wet process employs from 40 to 50 per cent., it may be said that the first named process embraces in its proportions the one of 33 per cent. which has been proposed in the preceding pages. It must be remarked, however, that the wet process has been applied by Mr. Higham to burnt kankars, which are thought by the writer to be richer in lime than the kankar from the Batala deposits, perhaps rich enough for being classed among the intermediate limes. If such is the case, (and the writer hopes that he may one day be given an occasion of ascertaining it,) a much greater proportion of water would probably be necessary for developing the full strength of the lime.

One important datum elicited during the experiments is, that kankar-cement loses nearly one-third of its bulk by being mixed with a quantity of water equal to about one-third its weight.

It might be said that the above experiments have not been carried out with sufficient minuteness, and that exact science has not been much benefitted by them: this is admitted, but the writer of this paper has neither the time nor the means of working for exact science. He could do no more than begin to rescue a complicated question from the sea of chaotic ideas in which it is plunged, and giving to his younger colleagues a simple and practical rule sufficiently exact when applied to the materials experimented upon, or to their equivalents.

Coming back now to the subject of lime and súrkhí, we see, by referring to the 2nd Edition of the "Roorkee Treatise," that it bases the informations given about súrkhí on the experiments of General Treussart, and says, page 93, paragraph 96—" It is only by experiment that it can be determined what bricks make the best súrkhí or puzzolanas; for, as has been shown, an under-burnt or píla brick furnishes the best if it contains a certain proportion of lime, while the brick should be thoroughly burnt or pucka, if it contains no lime."

This advice would be perhaps excellent if we knew what the French General meant exactly by under-burnt clay or brick; the term is vague as far as we are concerned. For instance, we have three varieties of well-burnt bricks, the tenacities of which are different; fastidious masons might look upon the two best varieties only as well-burnt, and the inferior in strength as under-burnt. This is only an illustration, but it shows how necessary it is to be fixed on the value of a term.

The advice of the "Roorkee Treatise" is completed by a warning which is to be found at the end of the paragraph preceding the above-mentioned one; it says, that "the practical deduction to be drawn from some great accidents in France, is never to employ artificial puzzolanas for any works of importance where water charged with salt is likely to effect them." This warning seems to have been extracted from George R. Burnell's Elementary Treatise on Limes, Cements, Mortars, &c.," who adds—" It also shows how much care should be taken before employing new compounds in works of importance, for we see that in these cases no symptom of decay manifested itself during the first three or four years. Such want of precaution is the more culpable in England (let us add in India also) where we possess natural cements of such undoubted excellence, and where it would be so easy to procure the best hydraulic limes." "Of such undoubted excellence" is not yet the true expression for India, but the writer has no doubt that a few years more will place this fact beyond doubt.

As a case in point, showing the necessity of great caution, is the failure of all the specimens made here with stone-lime and súrkhí. The bricks made in this district generally contain a good percentage of lime, because the brick makers prefer the clays containing a small proportion of little bits of kankar, and specks of lime are generally to be found in fractured bricks; our under-burnt súrkhí made from these bricks should therefore be excellent; still all kinds of specimens made with it for the last six years have lost their tenacity, although they were made with good drinking water from a well, and were deposited for some time either in that well water or in canal water. Specimens made under the same conditions with kankar-cement alone or kankar-cement and river sand, are all sound and strong.

The *morale* of the above is, that on works where limestone and clay only can be procured, only the mixtures of stone-lime and súrkhí which have been tried during a sequence of years, or artificial hydraulic limes, should be trusted. The waters which are to be used for mortar, the water in which the work is to be laid, and the clays should be tested also, and the presence or absence of salts likely to affect the mixture ascertained.

Experiments on Concrete.

Trial of specimens gave the following results :—

TABLE V.

Materials employed	Percentage of Water used	Age of Specimens	Mean Tensile Strength	No. of Specimens broken
Two, by measure of kankar-cement burnt with úpla, and three raw kankar from Batala washed, ..	30 per cent. of weight of mixture,	80 days,	60 lbs. per square inch,	5
Materials as above, ..	..	2 years,	157 " "	5

Table IV. showing the strength of neat cement after two years to be from 218 to 265 lbs. per square inch, it follows from the comparison of these tensile strengths to that of concrete after two years, that the raw kankar enclosed by the cement is a source of weakness to it. This settles the question once—Which is the best proportion of cement for concrete made with the above materials? As far as they are concerned, the answer to this question is obviously—The more kankar-cement the better for the concrete.

If instead of kankar for ballast we use a more tenacious material conjunctively with kankar-cement, the question of what proportion is the best will be answered by the well known experiment of filling one measure with the ballast thoroughly soaked with water and thoroughly shaken down, and then finding with the help of water, the cubic contents of empty spaces between the pieces composing the ballast. If those pieces are broken in such a way that besides being held together by the cement they have a chance of forming a bond, the concrete will be nearly as tenacious as the unbroken material.

The tenacity of red bricks on the Bari Doab Canal runs as follows :—

Mean of 6 bricks in each case.

1. Tensile strength of well-burnt bricks (colour—dark-red)=198lbs. per square inch.
2. „ „ over-burnt „ („ purple)= 244 „ „ „
3. „ „ kinghar „ („ dark grey)= 327 „ „ „

From which it may be concluded that red bricks are inferior in tenacity to kankar-cement after two years, that purple bricks are about equal to it after the same lapse of time, and kinghar bricks superior to it under the same condition of time, but probably only equal to the cement when it has attained its ultimate induration.

The manufacture of several thousand cubic feet of concrete *in situ*, gave the following results in labour per 100 cubic feet concrete :—

		RS.	A.	P.
6 Ramming coolies, at 3 annas each, ...	=	1	2	0
3 Mixers, at 2 annas 6 pie each, ...	=	0	7	6
2·5 Carriers of mixed stuff, at 2 annas 6 pie each,	=	0	6	3
2 Carriers of dry materials with a lead of 100 feet, at 2 annas 6 pie each, ...	=	0	5	0
$\frac{3}{8}$ Mason for levelling the layers before ramming, at 8 annas each,...	=	0	3	0
1 Bhistí, at 3 annas, ...	=	0	3	0
1 Mate, at 3 annas, ...	=	0	3	0
Total labour for making 100 cubic feet concrete,...	=	2	13	9

This of course does not include the labour for encasing the walls, which may be done in a variety of ways.

Other details of manufacture were as follows :—The rammers weighed 16 lbs.; the layers, before ramming, were from 4 to 4·5 inches thick; the cement was burnt kankar from Batala; the ballast was over-burnt and kinghar bricks broken in pieces from 1 inch to 2 inches in the longest axis, to which was added the small pieces of burnt cement which the men pounding the cement with mallets could not break.

The proportion of cement to ballast was one to two; the amount of water used was about 27 lbs. per cubic foot or per maund of cement.

When the ballast is, as described above, 165 cubic feet materials *i. e.*, 55 cubic feet cement and 110 cubic feet ballast, are required for making 100 cubic feet concrete.

Manufacture of Natural Cement.

A large quantity of kankar-cement was manufactured in the following manner:—

First, with the common native úpla kilns, in which a good disposition of the layers appeared to be for 1,000 cubic feet kankar as shown in the rough sketch, *see Fig.* 1, *Plate* XLV.

The loading, burning, and picking out the well-burnt kankar from the ashes took about nine days, at the following cost for labour:—

Loading the kiln and plastering the outside,..	@ 12 as. per	100 cubic	feet	raw	kankar.
Firing and watching fire, ...	@ 1 „	„	„	„	
Picking out the well-burnt kankar, ..	@ 13 „	„	„	„	

Total cost of labour per 100 cubic feet raw kankar, ... = Rs. 1-10

These rates are the lowest ever obtained by the writer. The petty contractors, unwilling at first to accept them, took them at last readily enough.

Second, with wood and úpla cakes laid in the intervals between the pieces. Mr. Higham, in his review of the writer's reports, says, paragraph 14, that "the method and cost of burning kankar by wood fuel has hardly been noticed by Mr. Nielly." The reason why such burning was not noticed was the want of a proper occasion for burning kankar with wood. Such occasion was furnished by the stock of úpla cakes in the neighbourhood of the kilns, within a circle of 10 or 12 miles having been soon exhausted, it became therefore necessary to use wood from the canal forests, notwithstanding the inexperience of the writer and of the native subordinates under him, in using wood for burning kankar.

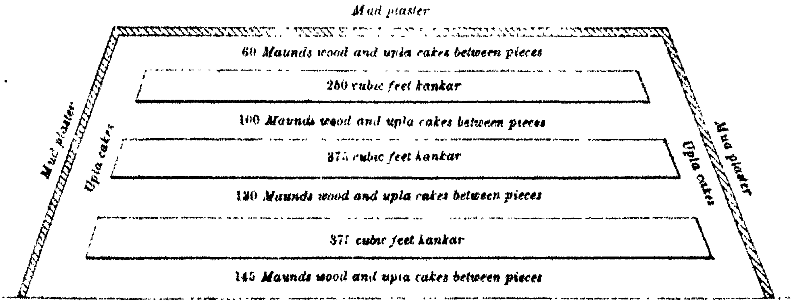
Woods of several kinds were then employed in pieces 5 or 6 feet in length, and of breadth not greater than 6 or 7 inches. Bigger logs were split in two or four pieces according to the size of the tree. In the intervals between the pieces of wood, cakes of úpla were laid to help the wood in taking fire and burning slowly. A good disposition of layers in kilns was found to be as shown in the sketch, *vide Fig.* 2, *Plate* XLV.

The quanty of fuel used was, per kiln, 485 maunds wood, and also 325

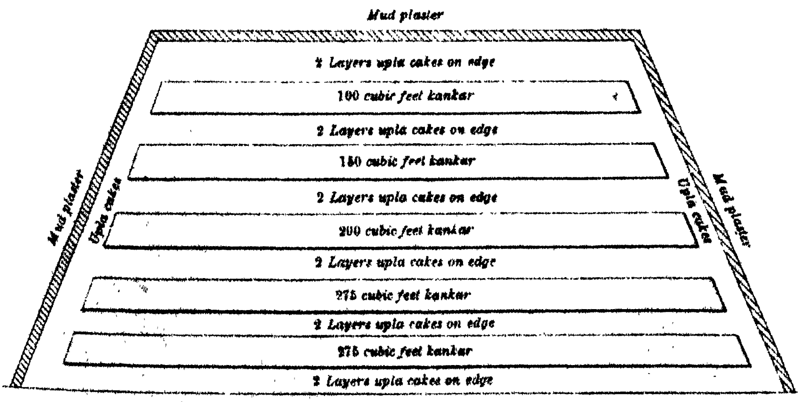
KANKAR LIMES AND CEMENTS, BARI DOAB CANAL.

Manufacture of Natural Cement.

BURNING OF KANKAR WITH UPLA CAKES.



BURNING OF KANKAR WITH WOOD.



cubic feet úpla, so as to make about 50 maunds of fuel per 100 cubic feet kankar. Upla weighs about 20 maunds per 100 cubic feet.

The weighing of wood, loading kiln, burning and picking out the well-burnt kankar, took about 15 days, all the fuel being thoroughly dry as it ought to be. A peculiar feature of these kilns is, that the wood must be first of all converted into charcoal, and slowly burnt as such; so any tendency of the wood to burst into flames must be well checked, and the free entrance of air in the kiln prevented by plastering. The cost of labour is—

Loading and plastering the outside, ..	@ 12 as.	per	100	cubic feet	raw kankar.
Firing and watching fires, ...	@ 1	"	"	"	"
Picking out the well-burnt kankar, ..	@ 11	"	"	"	"

Total cost of labour per 100 cubic feet raw kankar, = Rs. 1-8-6

The percentage of under-burnt is variable and generally large, owing to the want of homogeneousness in the raw material.

The denomination of kankar-cements adopted in this, and in previous reports for the Batala, and several other burnt kankars, has been objected to, and the authority of Rankine is brought forward in support of that objection. The "revised fifth edition" of Rankine's Manual of Civil Engineering has been consulted, and the quotations brought forward in favour of the objection must have been omitted in the above-mentioned edition, as they could not be found in it.* What was found was, at page 369, the following definitions of cements: "Cements produced from stones containing from 40 to 60 per cent. of silicates, which do not slake, and which harden quickly under water." Our so-called kankar-lime correspond exactly to the above definition, as it may be seen by referring to the analyses by Mohr's process in one of undersigned's previous reports; the Batala kankar-cement does not slake, and the setting activity of this cement is so great, that it begins immediately after mixing it with water, so the mason who uses it, and to whom it is served ground dry, must be carefully warned not to mix with water more than he can lay at once in the work. This is precisely the reason why the term cement is again advocated, because the writer wants by teaching a new and correct term to the native mason, teach him at the same time a new and correct way

* The quotation relative to the practical test was found afterwards. It may be answered to it that if Rankine had known the extremely simple means of analyzing and classifying proposed in these pages, he would not have recommended such unsafe guides as finger tests to scientific men.

of treating the cementing material to which the term is applied, and impress upon his mind that this kind of chúna called cement, loses its value if allowed to harden even for ten minutes in his mortar box before it is laid in the work.

As stated in a previous paper, it is admitted, however, that many burnt kankars may be classified among the hydraulic limes and treated as such, but many also of the burnt kankars are quick-setting natural cements of more or less ultimate strength; and it will be a great gain to call them so, because the mode of mixing them with water on the works is different from the mode adopted for hydraulic limes.

Experiments on Artificial Hydraulic Limes.

Experiments on these limes were undertaken with the view of restoring cementing strength to a large stock of old lime and old under-burnt súrkhí, the actual tensile strengths of which are given in Table III. Sample cakes were manufactured with the materials well ground and sifted through sieve 3,600 meshes to the inch, and in the following proportions:—

First—1 part in bulk of stone-lime to 1 of súrkhí.
Second—2 „ „ „ to 3 „
Third—1 „ „ „ to 2 „
Fourth—1 „ „ „ to 4 „ for puzzolana.

The above specimens were burnt in a flame kiln fed with wood, and produced in each case three kinds of burnt cakes, namely:—

One under-burnt kind of a light pink colour.
One well-burnt of a light straw colour.
One over-burnt of a grey colour.

The under-burnt and over-burnt were tried and gave bad results.

The results given by the well-burnt samples are—

TABLE VI.

Materials employed	Age of Specimens	Mean Tensile Strength	No. of Specimens broken
1. 1 stone-lime to 1 súrkhi, ..	14 months,	28 lbs. per square inch,	3
2. 2 „ „ to 3 „ ..	„	61 „ „	5
3. 1 „ „ to 2 „ ..	„	53 „ „	5
4. 3 puzzolana to 2 old stone-lime, ...	„	17 „ „	6

If the second result of this table is compared to the first result in Table III., it will be seen that re-burning has imparted to the mixture of old stone-lime and píla súrkhí a strength more than double the strength given in Table III., result first, and has probably imparted to it a chance of longevity. The hydraulic activity and the rapidity of induration of these samples being slow, their tenacity was not tried for several months. As the cost of manufacturing artificial hydraulic limes, without mechanical power for grinding and sifting the materials, is very great, it has been proved in a previous report, that it would be advantageous in a pecuniary point of view, to sell the old materials, and use kankar-cement on the Bari Doab Canal, as long as our fast-diminishing mineral wealth in kankar has not been exhausted by road-making.

A. N.

No. CCXLIV.

NOTE ON PLANTING AND TENDING TREES IN ROAD AVENUES AND TOPES IN INDIA.

By E. A. Parsick, Esq., C.E., F.G.S.

The primary object in planting trees along roads is to break their monotony, and to afford shelter to wayfarers, but there are other considerations, which, owing to the absence of well established data, are hardly worth recording; for instance, trees are stated to prevent accumulations of sand and dust on the road surface, and to benefit metalled roads by protecting them from the deteriorating effects of extreme solar heat, &c. On most fair-weather roads, trees could with advantage be so planted as to indicate their boundaries, and road avenues generally might in a great measure be rendered self-supporting by a judicious selection of valuable fruit trees, the produce of which might be farmed out on the double condition of payment and tending, thus securing a fixed annual revenue, and a considerable saving in establishment.

It is an open question whether avenues or topes are the more suitable. For the former, though yielding continuous shade and relief to the eye, are more expensive and difficult to tend, while the latter, placed usually at every third mile, fail to divest intermediate lengths of road of a barren and uninviting appearance, though they involve less outlay in both planting and maintenance, and afford more substantial immunity from the sun's rays, owing to their greater density.

Perhaps the best solution of this difficulty, where land is not valuable, would be to adopt both avenues and topes; each of the latter three acres in area, occurring at intervals of five miles, could also be used as nurseries, and should be provided with one or more wells or tanks, for the double purpose of supplying nourishment to young seedlings, and drinking water to travellers; the former might consist of trees planted 20 feet apart on both sides of the road along the centre of the berms or cesses. Where land is valuable, the area of each tope might be decreased to 1 acre, and in most cities topes would have to be dispensed with altogether.

The larger topes might have the dimensions $660' \times 198' = 3$ acres, and the smaller $220' \times 198' = 1$ acre, the greater dimension in each being parallel to the road, and out of the lesser dimension, 48 feet being reserved at the back for nurseries: thus the larger topes and nurseries would be $660' \times 150'$ and $660' \times 48'$, respectively, and the smaller ones $220' \times 150'$ and $220' \times 48'$, respectively.

It may not be always advisable to place the topes at uniform intervals of five miles, as river or nullah crossings, or the presence of old tanks or wells may be found more economical than any other sites, but these should be accepted after careful inquiry, for if the supply of water is not constant, nothing will be gained.

A tope is also very acceptable at each bend, if it be sufficiently thick to conceal the road beyond it, and trees might be planted in such positions without any reference to the five mile nursery topes, and in fact the same procedure might be adopted at each nullah or river crossing, and at each old tank or well, but in these cases, trees enough to shelter a few travellers would be sufficient.

Other advantages attending the planting of topes and nurseries at every five miles are—

1. Foot passengers and carts in their stereotyped journeys of 20 miles per diem, starting from one tope in the morning, could rest under shelter three times during the day, and then in the evening reach the 20th mile tope, where they could put up all night.

2. Shops would soon spring up close to the topes, and by thus making them more attractive and frequented, would materially aid the Police in protecting travellers, and in fact would almost make Police 'surveillance' unnecessary, as a large number of wayfarers collected on one spot can generally take care of themselves.

3. No better sites could be found for Inspection Bungalows and Police Stations.

4. Seedlings from the nurseries would not require to be carried more than 2½ miles, and the road nursery and avenue establishments could at a small expenditure be furnished with permanent head-quarters without any detriment to their efficiency.

5. Ready made sites at convenient distances would be found for the encampments of district and other officers, which is by no means an unimportant consideration in these litigious times, when objections are not unfrequently raised by proprietors to their topes being so occupied.

6. Very favourable opportunities would be afforded for studying the growth of trees and other matters connected with arboriculture. After the sites of nurseries have been fixed, the selection, planting, and tending of trees will require the most anxious consideration.

II. SELECTION.—The most important points under this heading are the selection of—

1. Trees not easily snapped or broken by high winds.

2. Trees noted for longevity and maturing quickly.

3. Trees graceful in form, luxuriant in foliage, and beautiful in blossom.

4. Trees retaining their foliage for a maximum period.

5. Trees yielding either edible fruit or other products valuable in the arts and manufactures.

6. Trees of sufficient height to cast their shadows on the road during the greater part of the day.

7. Trees with no objection to grow in any soil.

8. Trees that yield a minimum amount of litter.

9. Trees not subject to the depredations of either animal or vegetable parasites.

10. Trees least affected by climatic changes.

11. Trees yielding good timber and fuel—this condition is, however, hardly a '*sine quâ non*' in avenue trees.

A very moderate acquaintance with arboriculture is sufficient to show the hopelessness of finding to perfection all the above conditions in any great number of trees, and unfortunately some of the most desirable are the least suitable; thus, the 'Bukain' or Persian Lilac, is a rapid grower, highly ornamental, and yields luxuriant lilac flowers, but it is leafless for many months each year, is easily broken by high winds, and furnishes a very inferior wood; the 'Amaltas' with its laburnum-like yellow blossoms has few rivals in point of beauty, but it is small in stature, though yielding a useful wood; the 'Uzer' is rapid in growth and shady when in foliage, but when leafless is very unsightly, owing to its being covered with the cobweb-like habitations of some caterpillar, and its wood is light and perishable; the 'Sirris' grows quickly and to a great height, yields handsome foliage, sweet scented flowers, and good timber, but its large seed-pods fall in thousands, and make a road untidy.

Due regard, however, being paid to position, soil, and purpose, enough trees exist for all requirements, and the extreme beauty of even some of those just named, may, under certain restrictions, be ample apology for their admission into the most select umbrageous society.

In the Appendices will be found details of trees—

I. Suitable for avenues only, whether in cities or extra-mural.

II. Suitable for both avenues and topes.

III. Suitable for city avenues only.

IV. Unsuitable for avenues.

The weeping willow has not been entered in any of the above lists, but if planted along the high water mark of a river, near human habitations, it would relieve the banks of their dull monotony.

A more general cultivation of the bamboo with its luxuriant foliage and graceful form is recommended, as besides being a highly ornamental addition to any avenue, it yields a stem very useful for roadwork, if only as shafts for rammers.

II. Planting.—Under this heading is included—

1. Sowing of seeds.
2. Nurture of young seedlings in nurseries.
3. Removing seedlings from nurseries and planting them in their permanent positions at the roadside.

On many roads, nurseries existing at convenient intervals have originally been started by either transplanting very young seedlings or by sowing, and the requirements of the avenues have been met from these plots by removing young plants as required at all stages of growth, and at any time of the year. As a rule the plots are thickly sown, and the young plants packed closely together, lead a sickly existence, till roughly removed (without much regard to broken roots or age) and planted at the roadside in high "thallas," where not unfrequently they wither away: this fate is shared by all but one of the 20 or 30 seedlings which replace them in succession, and this the last takes root owing to the lucky chance of having been planted at a favourable time, and to its being hardier than its departed kin; but its trials are by no means over, for the temperature of the water allowed to collect and stagnate in its mud prison house "thallah," is raised to almost boiling point by the hot sun in July and August, and the plant dies.

The process of replacing just described is again commenced and possibly repeated 50 times before some exceptionally fortunate, but badly selected seedling, escapes these trials of infancy, and eventually for six months each year, leads a leafless existence; useless, hideous, and stunted—a monument of fruitless expenditure, neglect, and want of judgment.

Most of the above failures and waste would be avoided by adopting what may be called the "pot-system," which steers clear of the evils attending transplanting, and ensures to each seedling a robust youth and manhood, by bestowing on its infancy the most tender care and attention.

That sowing leads to better results than transplanting, is acknowledged by such authorities as Miller, Marshall, Evelyn, Emmericle, Speechly, Lang and Yule, and the relative advantages of the two systems are thus summed up by Dr. Geo. Henderson in a tract entitled, "Arboriculture in the Punjab."

Transplanting system.	*Sowing or Pot-system.*
1. Large percentage ultimately lost.	1. Few trees lost.
2. Small outlay at first.	2. Larger outlay at first.
3. Ultimate cost at least eight annas a tree.	3. At most two annas.
4. Large transplanting establishment.	4. Few extra men required.
5. Transplanting must be slowly and carefully done, and only at certain seasons.	5. Any coolies can lift and load on a cart 1,000 a day, and two men can plant out that number at any season without risk.
6. Transplanting checks growth one season, which entails one season longer watering and protection.	6. Removal in pots and planting at the roadside does not check growth.
7. Three years watering and protection required.	7. Occasional watering from July till September, and regular watering only during next hot weather. Protection 18 months at most.
8. Transplanting to any distance difficult. Can only be safely done on "charpaes."	8. Transport easy and safe to any distance, at any season.

The best procurable seeds having been obtained with due regard to the rules laid down under the heading "selection," they should be sown in conoidal earthen pots with diameters of 9 and 6 inches at top and bottom, respectively, 12 inches in height, and with holes in their bottoms, 1 inch in diameter.

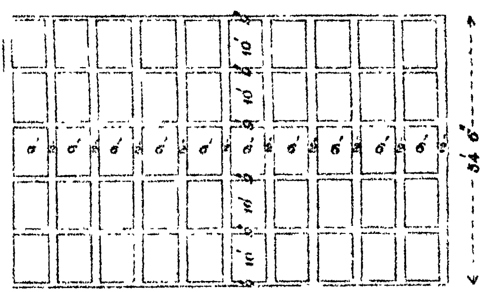
The pots should be first filled with a layer, one inch deep, of broken bricks and charcoal, to secure good drainage, and over this should be lightly laid the best soil procurable, to a depth one inch below the top of each pot.

The soil used should be free from saline matter and ordure of every description: loam containing 75 per cent. of sand makes the best pot soil, and if this cannot be found, sand should be added till this percentage is secured.

The pots being thus prepared, only 10 per cent. of them should be thickly sown with seeds, of which no two sorts should be put into the same pot.

When the seedlings have got their first pair of leaves, and are from 1½ to 2 inches high, they will be ready for transplanting into the pots, in which they are to grow, in each of which only one healthy looking plant should be set, the earth round it being carefully pressed down, and water being liberally supplied.

The young plants thus disposed of should be kept in the shade, and constantly watered for seven days at least, at the end of which time, those presenting a healthy appearance should be placed out in the open with their pots in plots, consisting of parallel ridges each 1 foot high, 2 feet wide, and 54½ feet long, placed 6 feet apart, with transverse ridges, 1 foot high and 9 inches wide, placed 10 feet apart at right angles to them.



Each plot will then be 82′ × 54½′ with 50 beds, each 10′ × 6′, in which should be placed symmetrically 20 pots, all bedded 3 inches into the soil: hence each plot will hold 50 × 20 = 1,000 pots, and in each nursery there may be as many such plots as required.

The beds should now be flooded twice a week, till all the pots are completely submerged, but no water should be let into the beds, till after 4 P. M., when the sun is going down, otherwise many of the plants will be killed.

Neither rain, nor the water with which the beds have been flooded, should be allowed to remain in them, between 9 A. M. and 4 P. M., and with the view of securing the means for speedy drainage, by a simple breach in any of the ridges, these should be built wholly above the level of the ground.

In cloudy or rainy weather, a small quantity of liquid manure may, when the plants are fairly established, be sprinkled on the pots at the time of flooding the beds.

No weeds should be allowed to grow in the beds.

The young plants having been thus carefully tended for six months, will be about 3 feet high, and ready for removal to the roadside, and to receive them, holes 3′ × 3′ × 3′, should be dug at least three months before they are required, and these holes should be kept flooded with water. At the time of planting, the pots should be broken, and after the young trees have been placed in the holes made for them, saucers 4 feet in diameter, and 3 inches in depth, should be formed round them, and not the ordinary "thallas." Each saucer, may with advantage be enclosed by a light frame of thorns, bamboos, or brushwood, to secure the young plant in it, against injury from animals.

III. TENDING.—The plants having found their way to the roadside, about the end of September, cannot yet be left to their own resources, but will require careful tending for several years in reference to watering, protection from cattle, weeding, &c.

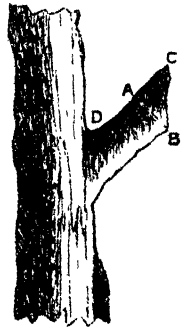
The plants should be watered occasionally to the end of September, and regularly during the next hot season, ditch being used in preference to well water, as the former contains more nourishment.

The utmost care should be taken that no water be allowed to stagnate round the trees, and also that no water be allowed to touch the trees during the heat of the day.

No weeds should be allowed within the saucers as long as they are necessary, *i. e.*, until the trees are at least two years old.

Pruning should be avoided as much as possible, but when necessary to admit of the free passage of traffic, it should be done in December and

January; on young trees with a pruning knife, and on old trees with a saw, the branches being removed at a distance from the stems equal to their circumference, *i.e.*, DC = circumference at AB.



The cut should be vertical as at BC, which by preventing the lodgment of water, saves the tree from decay.

The section with a pruning knife should be made upwards, and that with a saw downwards, care being taken in each case to incise the bark right round in the line of section, and to make an angular under-cut, with the view of preventing injury to both the bark and tissue of the portion not requiring removal.

APPENDICES.

Appendix No. I.

List of Trees suitable for Avenues only, whether in Cities or Extra-Mural.

Botanical name.	Native name.	English name.	Brief description.
Acacia Elata, ..	Seet,	Dhoon Sirris.	A tall handsome tree, yielding a hard durable wood, used for posts and furniture.
Acacia Speciosa, ..	Sirris or Sirsa,	?	A rapid and stragling grower, with handsome foliage and sweet scented flowers. Yields good timber, used for naves of wheels, pestles, mortars and fuel. Its seed-pods when falling make a road untidy. Matures in 20 years with a diameter of 18 inches.
Azadarachta Indica, ..	Nim,	Bead-tree.	Grows well and quickly almost anywhere, with beautiful and shady foliage. It attains a height of from 40 to 50 feet, with a diameter of from 20 to 24 inches. Its timber though brittle when dry, is much used on account of its fragrance, for native door-frames, and on account of the fine polish it bears for joiner's works. The leaves and bark are used medicinally. Its white flowers are highly scented, and from its bead-like yellow fruit, oil is extracted, said to be fatal to lice. It matures in 50 years.
Bambusa Arundinacea,	Bans,	Bamboo.	This growth is too well known to require description.
Barringtonia Racemosa, ..	Caddapah,	?	Yields rose coloured showy flowers, and a close grained wood, used in house-building, cart framing, and for railway sleepers.
Bombax Malabaricum,	Simul,	Cotton-tree.	This noble rapid growing tree is leafless for some time each year, and matures in 100 years, with a diameter of 40 inches. Its wood is only used for packing cases, tea chests, and camel trunks, and from its entire trunk, some of the largest and safest canoes are scooped out.

Botanical name.	Native name.	English name.	Brief description.
Casuarina Muricata,	?	Tenasserim Fir-tree.	Grows almost any where, but with great rapidity in sandy soil. Is handsome, large, fir-like, very shady, and yields a strong, stiff timber.
Cedrela Toona,	Toon,	Bastard Cedar.	Prefers sandy soil, and is a large, sightly, shady tree. The timber bears a high polish, and is a good substitute for Mahogany in the manufacture of furniture. The bark is a good substitute for Peruvian bark.
Conocarpus Latifolius,	Baklí,	?	A large showy tree, whose timber is much used for axle-trees and carriage shafts.
Cupressus Torulosa, ..	Deodar,	?	A handsome lofty tree, yielding good timber, though unsuitable for building purposes till well seasoned, as when first felled it contains a large amount of turpentine.
Dalbergia Sissoo, ..	Sissú or Shisham.	?	Grows well any where and very rapidly. A strikingly beautiful and large tree. Wood strong, durable, close-grained, and much used for furniture. Matures in 80 years, with a diameter of 18 inches.
Ficus Elastica, ..	Caoutchouc tree,	Indian Rubber tree.	A fine large very shady tree.
Ficus Indica, ..	Burgud,	Banyan.	One of the best Indian trees for avenues, as it covers more area in a given time, than any other tree. This is the "fig-tree" of Milton's Paradise Lost. Its timber is chiefly useful under water for well-curbs, &c., and the wood of its hanging roots is used for yokes, tent poles, &c.
Ficus Religiosa,	Pipul,	Poplar-leaved Fig-tree.	A fine avenue tree growing anywhere, attains a great size, and is very handsome, and shade-giving. Its wood is used by the natives for the frames of carts and for door-posts. Owing to its sacred character one or two might be planted near each well intended for travellers.

Botanical name.	Native name.	English name.	Brief description.
Ficus Venosa, ..	Pakur,	Vein-leaved Fig-tree.	A handsome tree with lots of shade, well worthy of more extensive use in avenues.
Gurelina Arborea, ..	Gomar,	?	A large straight tree bearing handsome flowers. Its wood is used for carriage-panels, palkis, &c.
Guatteria Longifolia,	Asoka,	?	A handsome tree, with beautiful foliage and dense shade. It yields a wood used for drum cylinders only.
Hardwickia Binata, ..	Ancha,	?	An elegant, tall, erect tree, yielding a wood used for posts, piles, and for ornamental turnery.
Inga Lucida, ..	Ta-myen,	Iron-wood-tree.	A rapid growing tree attaining a great height, with magnificent shady foliage and sweet scented blossoms. It yields the iron-wood of Burmah.
Lagerstraemia Reginæ,	Yarul,	?	A large tree, very ornamental when covered with luxuriant purple blossoms. Its timber is much used for boats, carts, house-building, &c.
Michelia Champaca,..	Chumpa,	?	A large tree with handsome foliage and flowers, attaining in places a girth of 50 feet. Its wood takes a beautiful polish, and makes handsome tables.
Mimusops Elengi, ..	Bakula,	?	A very ornamental tree, noted for beautiful foliage and fragrant white flowers. The wood takes a good polish, and is used for furniture and house-building.
Nauclea Cadumba, ..	Kuddum,	?	A tall fine looking tree with orange coloured blossoms, sometimes reaching 80 feet in height and 12 feet in girth. Its wood is used for furniture and building purposes.
Nauclea Parviflora, ..	Kaim,	?	A large tree yielding a fine-grained wood, used for flooring planks, packing boxes, and cabinet purposes.

Botanical name.	Native name.	English name.	Brief description.
Pongamia Glabra, ..	Kurunj,	?	Attains the height of 40 feet, with evergreen shining foliage. Its wood is used for solid wheels and fuel. Its boughs and leaves make good manure.
Pterocarpus Marsupium, ..	Bejasal,	?	A beautiful large tree, yielding wood much used for carts, house-building and railway sleepers.
Pterospermum Acerifolium.	?	?	A lofty, handsome, shady tree. Its wood is as valuable as Teak.
Putranjiya Roxburghii, ..	Jeapota,	?	A large and shady tree with straight erect trunk. Its wood is well suited for turning.
Sonneratia Apetala, ..	Khoura,	?	A large and elegant tree. Its wood is used for beer and wine packing cases, and for rough house-building purposes.
Terminalia Belerica,..	Bahíra,	?	A very large tree, with a straight trunk and spreading head, yielding flowers with a peculiar offensive smell. Its timber is not used in carpentry.
Thespesia Populnea,..	Parus,	Portia-tree.	A handsome tree. When produced from cuttings, it grows rapidly, but yields a hollow trunk fit for firewood only; when produced from seedlings, its wood is compact and strong, and fit for gun-stocks and furniture.

APPENDIX No. II.

List of Trees suitable for both Avenues and Topes.

Botanical name.	Native name.	English name.	Brief description.
Artocarpus Integrifolia, ..	Kantul,	Jack-tree.	A rapid grower, handsome, and attaining a great size. Its fruit is much esteemed by the natives, and its wood is used for furniture, musical instruments, &c.
Artocarpus Lacoocha,	Burhul,	Monkey-Jack.	Yields an orange coloured edible fruit, and a wood much used for the construction of canoes. From its roots a yellow dye is obtained.
Bassia Latifolia, ..	Mahwah,	?	Likes a dry soil on table land, and attains a large size when detached. Its white sweet-scented flowers are dried and eaten, and from its fruit, a valuable spirit is extracted, and also a much used oil. It attains a height of from 50 to 60 feet, with a diameter of about 4 feet, and its heart wood is hard, close-grained, heavy and durable.
Dillenia Speciosa, ..	Chulta,	Indian Dillenia.	A tall ornamental tree, with large fragrant white flowers. It yields a sub-acid edible fruit, and a wood much used for building and for gun-stocks.
Emblica Officinalis, ..	Aonla,	?	A large ornamental tree, yielding the 'Myrobalan' fruit, and a durable wood used for gun-stocks, furniture, boxes, &c. It is useful for well-curbs, as it does not decay under water.
Feronia Elephantum,	Kaitha,	Wood apple	A tall handsome tree, yielding a hard-shelled edible fruit. From the bark is manufactured 'East India Gum Arabic.' Its wood is hard and compact, and is used for building, for carts, and also for railway sleepers.

Botanical name.	Native name.	English name.	Brief description.
Ficus Glomerata, ..	Gúlur,	Glomerated Fig-tree.	Wide spreading and shady. Delights in moist soils, and yields an edible fruit. Its wood is durable under water, and is much used for well-curbs, but is useless for other purposes.
Mangifera Indica, ..	Am,	Mango.	Does not thrive in wet clayey soil; wide spreading, handsome and very shady. Yields a well-known edible fruit, and its wood though weak, and inferior, is much used for planks, door-frames and furniture.
Syzyginm Jambolanum, ..	Jamún,	?	Thrives best in rich sandy soil. Is a tall, handsome, stately tree, and yields a much prized plum-like fruit. The wood is very durable under water, and is also used for fuel.
Tamarindus Indica, ..	Imli,	Tamarind.	Grows anywhere, though very slowly. When full grown, is one of the handsomest and largest trees in India, and yields a marketable fruit, and valuable wood, used for brick-burning, and the manufacture of charcoal. Reaches maturity in 200 years, with a diameter of 20 inches.
Terminalia Chebula,..	Hulda,	?	A beautiful, lofty tree, with horizontal branches growing in tiers. Its fruit and galls are used by dyers, and its wood for house-building purposes.

Appendix No. III.

List of Trees suitable for sheltered positions in City and other Avenues.

Botanical name.	Native name.	English name.	Brief description.
Bauhinia Variegata,..	Kachnar,	?	This small-sized tree presents a lovely appearance when covered with pretty lilac flowers. Its hard and ebony-like wood is useful for furniture only.
Cathartocarpus Fistula,	Amaltas,	Purging Cassia.	Very ornamental and shady, and truly beautiful when covered with laburnum-like scented yellow blossoms. It however, never attains a very large size, but its wood is suitable for furniture.
Millingtonia Hortensis,	Angraji Bukain.	Cork-tree.	A rapid growing handsome tree, with lovely foliage, and white scented flowers. It yields a soft wood, useless except for fuel, is short lived, and is apt to be injured by storms.
Moringa Pterygosperma, ..	Saijnah,	?	Grows rapidly into a handsome tall shady tree, easily broken by high winds. Its wood is useless, but the young roots yield a good substitute for horse-radish.

Appendix No. IV.

List of Trees unsuitable for Avenues.

Botanical name.	Native name.	English name.	Brief description.
Acacia Arabica, ..	Babúl,	Gum-Arabic-tree.	Grows rapidly in most places, and appears to prefer the poorer soils. Is not very shady, and attains the height of from 30 to 35 feet, with a diameter of 2 feet. It scatters thorns on a road, and soon creates a jungle from the seeds it spreads about. Its wood is hard, compact, and durable, and is much used for carts, ploughs, mills, tent-pegs, &c. Its bark is used as a tan for leather, and it yields a gum somewhat inferior to that of the Egyptian thorn. It is sometimes sown on impoverished soil, subject to inundations, as a substitute for ordinary crops. By the time that silt renovates the soil, the babúl jungle is fit for selling, and the cultivator thus derives more profit than if he had left the land fallow.
Ailanthus Excelsa, ..	Urrer,	?	Rapid in growth, and shady when in foliage, but when leafless is very unsightly, owing to its being full of the cobweb-like habitations of some catterpillars. Its light and perishable wood is used for scabbards, &c.
Butea Frondosa, ..	Dhak,	?	Grows almost anywhere, and is often chosen for avenues on account of its deep red and orange coloured flowers. It is small in size, and its gnarled wood is best fitted for firewood, though from its fibre is twisted a very strong durable rope. It also yields the favourite gunpowder-charcoal, and from its flowers is manufactured a bright yellow dye.

Botanical name.	Native name.	English name.	Brief description.
Cordia Myxa, ..	Lasora,	?	Though a rapid grower, is not a suitable tree for avenues.
Erythrina Indica, ..	Dol Dhak,	Coral tree.	Grows to no great height, yields a profusion of scarlet blossoms, and produces a soft, light wood, from which toys, scabbards, &c., are commonly made.
Melia Azadarach, ..	Bukain,	Persian Lilac.	A highly ornamental rapid grower, yielding luxuriant lilac flowers, but leafless for many months, and easily broken by high winds. Its wood is useful for light furniture only.
Morus Indica, ..	Shah-tút,	Mulberry.	Large sized and rapid growing, but bare of leaves for several months each year. Its leaves are a favourite food for silk worms. It yields an edible fruit, and its yellow compact wood is much used for turning, and for burning purposes.

E. A. P.

No. CCXLV.

GRAPHIC DIAGRAMS FOR STRENGTH OF TEAK BEAMS.

[*Vide* Plates XLVI. to L.]

By Guilford L. Molesworth, Esq., *Consulting Engineer to Govt. for State Railways.*

The value of graphic diagrams for practical use is too well known to require any remark.

The diagrams accompanying this note were suggested by Mr. E. Herbert Stone's useful book of "Formulæ and Tables for facilitating the Calculation of Teak Beams," but, as in that book, separate diagrams are employed for each span, and those diagrams involve curved lines, it occurred to me that, by expressing the formulæ in terms of the ratio of the depth to the span, the formulæ might be simplified, and one diagram would suffice for all spans; and also that by making the scale for spans proportional to the *square* of the span, instead of directly as the span, the curves might be replaced by straight lines. The diagrams were originally prepared for teak beams, but, in order to make them more generally useful, I have added a set of scales for other timber, and it will be easy to construct for any other timber, not given, scales applicable to the diagram for teak.

I have thought it desirable to give diagrams for beams having a breadth one-half of their depth, as well as for those having a breadth of two-thirds. My reason for giving diagrams of the former proportion is because although the latter proportion is better for a beam, it is frequently found economical to cut two beams from a square balk, which cannot be effected with the former proportion.

There are three descriptions of diagrams—

1. For Transverse Strength.
2. For Stiffness.
3. For Weight.

The diagrams of transverse strength and stiffness are to be used to determine the depth of the beam: that diagram, which gives the lowest load as its result, being adopted; for a beam may have sufficient transverse strength, and be deficient in stiffness, or *vice versâ*.

The diagram for weight is intended to show at a glance how much the load is increased by the weight of the beam itself; the scale for the smaller spans is 10 times as large as that for the larger spans; the scale of spans in the diagrams for transverse strength and stiffness is in proportion to the square of the span; whilst the scale of spans in the diagram for weight is as the cube of the span; the diagrams for transverse strength are based on the assumption that the load is to be evenly distributed over the length of the span, with the factor of safety of 10.

The diagrams for stiffness are based on the assumption that the load, evenly distributed over the length of the span, should not produce a deflection exceeding $\frac{1}{40}$th of an inch per foot of span. As a rule, the diagrams for transverse strength should be used for deep beams, whilst those for stiffness should be used for shallow beams; but there are exceptions to this rule, when the modulus of elasticity is proportionally very low in comparison with the modulus of rupture; in such a case the diagram of stiffness must be used for all depths within the limits of the diagram.

In the case of the majority of timbers, there is a certain depth at which the formula for stiffness gives the same results as that for transverse strength. I have termed this the "limiting depth," and shown it approximately for each kind of timber on the sheet of scales; for depths exceeding this "limit," the diagrams for transverse strength are to be used, and for depths below this limit, the diagram for stiffness must be used.

The formulæ adopted in the construction of the diagrams are as follows:—

L = Safe load in lbs. distributed.

S = Clear span of beam in feet.

d = Depth of beam in feet.

b = Breadth of beam in feet.

N = Number of times the depth is contained in the span $= \frac{S}{d}$.

T = Modulus of rupture; being the breaking weight applied at the centre of a beam 12 inches long and 1 inch square supported at both ends. For values of T, *see* Table No. 1.

E = Modulus of elasticity; or that load which if applied to the centre of a beam 1 foot long, and 1 inch square, supported at both ends, will produce a deflection of 1 inch. For values of E, *see* Table No. 2.

K_T = Coefficient of transverse strength $= 0{\cdot}1 \left(\frac{12}{N}\right)^3$ for beams whose breadth = $\frac{1}{2}$ depth.

$= 0{\cdot}1333 \left(\frac{12}{N}\right)^3$ for beams whose breadth = $\frac{2}{3}$ depth.

K_E = Coefficient of stiffness. *See* Table No. 4.

$= {\cdot}02 \left(\frac{12}{N}\right)^4$ in beams whose breadth = $\frac{1}{2}$ depth.

$= {\cdot}02667 \left(\frac{12}{N}\right)^4$ in beams whose breadth = $\frac{2}{3}$ depth.

W = Weight in lbs. of a beam whose length is equal to the span.

w = Weight in lbs. of a cubic foot of timber. *See* Table No. 3.

k = Coefficient of weight varying with depth of beam.

$= \frac{0{\cdot}5}{N^2}$, for beams whose breadth is $\frac{1}{2}$ their depth.

$= \frac{0{\cdot}6667}{N^2}$, for beams whose breadth is $\frac{2}{3}$ „ „

$L = S^2 \times T \,.\, K_T$, for transverse strength.

$L = S^2 \times E \,.\, K_E$, for stiffness.

$W = S^3 k \,.\, w$.

In Table No. 3, I have given the scientific names of the timber, in order to identify the character, as many species which are wholly distinct from each other have the same popular name.

As the modulus of rupture and elasticity, and the weight of timber varies considerably, according to different authors, I have thought it desirable to add tables of these data, as given by different authors, and also those which I have adopted in the construction of the diagrams and scales, and in order to facilitate the calculation of diagrams for other timbers than those given in the sheet of scales, I have added a table of coefficients.

Table No. 1, gives the values of T; or modulus of rupture.

„ No. 2, „ values of E; or modulus of elasticity.

„ No. 3, „ weight of timber of different kinds, or w.

„ No. 4, „ values of $T \,.\, K_T$ and $E \,.\, K_E$, or the coefficients of transverse strength and stiffness of different kinds of timber, multiplied by their respective moduli of rupture or elasticity, as the case may be.

Table No. 1.

Value of T; *or Modulus of Rupture, being the breaking weight applied to the centre of a beam* 12 *inches long and* 1 *inch square, supported at both ends.*

	Adopted	Barlow From To	Rankine From To	Roorkee Treatise From To	Moles-worth From To	Stoney
Jarrah, ...	1124	..	1124	..	..	..
Johore teak, ...	1077	..	1077	..	..	..
Paloo, ...	1050	..	1050	944	..	..
Iron-wood, (Ceylon,) ..	1040	..	994	..	1000	..
Satin wood, ...	950	..	1044	870	1033	..
Sál, ...	926	..	905-1150	769-880	..	..
Palmyra, ...	880	..	816	944	..	..
Babool, ...	880	..	..	876-884	..	..
Halmililie, ...	844	..	844	784	..	..
Iron-wood, (Burmah), ..	836	..	..	836	..	..
Teak, ...	800	820	640-820	683-814	697-703	703
Sissoo, ...	760	..	..	706-807	..	..
Jack, ...	750	..	611	788	610	..
Ash, ...	750	668	667-778	..	667-1000	675
Neem, ...	736	..	..	720-752	..	..
Mililie, ...	722	..	772	..	..	..
Ebony, (Ceylon),.. ..	722	..	722	..	..	..
Mee, ...	722	..	722	730	..	..
Oak, (Himalayan,) ..	670	..	..	670	..	..
Poon, ...	640	740	739	612	..	651
*Cheer, ...	630	..	..	582-735	..	..
Birch, ...	630	679	550	..	633-643	643
Mahogany, (Honduras,)..	615	..	639	..	551-633	573
Cocoanut,..	608	..	..	608	..	..
Oak, (British,)	608	352-753	555-727	..	533-663	565
Mango, ...	592	..	..	560-682	..	..
Chestnut,..	590	..	592	..	590	..
Oak, (American red,) ..	576	..	589	..	..	562
Beech, ...	570	519	500-667	..	400-667	519
Toon, ...	560	..	..	560	..	..
Spruce fir, ...	560	..	530-633	..	496	449
Deodar, ...	552	..	..	456-655	..	..
Sycamore,..	533	..	533	..	..	..
Memel, ...	500	577	..	..	447	449
Oak, (Dantzic,)	490	383-486	487	..	..	506
Red pine, ...	450	443	394-539	..	400-510	509
Cedar of Lebanon, ..	450	..	411	..	433-477	498
Larch, ...	400	278-383	277-556	..	443-553	445
Elm, ...	370	329-403	333-538	..	257-366	261

* There is an order of the Punjab Government against the use of Cheer on account of its liability to snap suddenly.

Table No. 3.

Weight of Timber in lbs. per cubic foot, or value of w.

	Adopted		Barlow	Rankine	Roorkee Treatise	Molesworth	Stoney	Cresy
	$\frac{45}{w}$	w						
Jarrah, (*Eucalyptus Marginata,*)	·763	59	..	59	..	..	..	..
Johore teak, (*Baloo,*)	·682	66	..	..	..	62-70	..	..
Paloo, (*Mimusops Hexandra,*) ..	·652	69	..	68	70	..	..	..
Iron-wood, (*Mesua Nagaha,*) ..	·634	71	..	72	..	71	..	..
Satin wood, (*Chloroxylon Swietenia,*)	·750	60	..	55	60	60	59	..
Sal, (*Shorea Robusta,*)	·750	60	..	60	55	..	62	..
Palmyra, (*Borassus Flabelliformis,*)	·693	65	..	65	65	..	..	..
Babool, (*Acacia Arabica,*) ..	·833	54	..	..	54	..	..	..
Halmilille, (*Berrya Ammonilla,*)	·900	50	..	48	50	..	..	..
Iron-wood, Burmah, (*Inga Xylocarpa,*)	·776	58	..	..	58	..	..	..
Teak, (*Tectona Grandis,*) ..	1·000	45	46-47	41-55	42-45	46-54	37-52	..
Sissoo, (*Dalbergia Sissoo,*) ..	·865	52	..	..	50	..	55	..
Jack, (*Artocarpus Integrifolia,*)	1·072	42	..	42	44	42	..	..
Ash, (*Fraxinus Excelsior,*) ..	1·000	45	44-48	47	..	42-47	..	50
Neem, (*Azadarachta Indica,*) ..	·900	50	..	..	50	..	..	..
Milille, (*Vitex Altissima,*) ..	·804	56	..	56	..	..	..	..
Ebony, (*Diospyros Ebenus,*) ..	·625	72	..	71	..	74	..	..
Mee, (*Bassia Longifolia,*) ..	·750	60	..	61	60	..	..	..
Oak, Himalayan, (*Quercus Semicarpifolia,*)	..	..	..	..	..	..	..	..
Poon, (*Calophyllum Angustifolium*)	1·216	37	35-37	36	45	..	40	..
Cheer, (*Pinus Longifolia,*) ..	1·500	30	..	..	..	27-34	..	..
Birch, (*Betula Alba,*)	1·000	45	39-49	44	..	44-45	..	45
Mahogany, (*Swietenia Mahagoni,*)	1·285	35	..	35	..	35	35	35-53
Cocoanut, (*Cocos Nucifera,*) ..	·643	70	..	..	70	..	..	..
Oak, British, (*Quercus Sessiliflora*) and *Quercus Robur,*)	·900	50	47-62	43-62	..	48-58	50-55	51-52
Mango, (*Mangifera Indica,*) ..	1·072	42	..	..	42	..	..	..
Chestnut, (*Castanea Vesca,*) ..	1·185	38	..	33	..	38	..	41
Oak, American red, (*Quercus Rubra,*)	·958	47	..	..	..	..	47	..
Poplar, ...	1·153	39	..	..	..	..	..	39
Beech, (*Fagus Sylvatica,*) ..	1·046	43	39-44	43	..	43	..	50
Toon, (*Cedrela Toona,*)	1·451	31	..	..	31	..	..	..
Spruce Fir, (*Abies Excelsa,*) ..	1·406	32	..	30-44	..	32	..	..
Deodar, (*Cedrus Deodara,*) ..	1·364	33	..	..	..	31-35	..	..
Sycamore, (*Acer Pseudo-Platanus,*)	1·125	40	..	37	..	..	40	48
Memel, (*Pinus Silvestris,*) ..	1·285	35	37	..	..	34	34-35	..
Oak, Dantzic, (*Quercus Sessiliflora,*)	·978	46	44-49	..	..	..	..	..
Red Pine, (*Pinus Silvestris,*) ..	1·125	40	41-42	30-44	..	36-41	..	31-41
Cedar of Lebanon, (*Cedrus Libani,*)	1·500	30	..	31	..	30	..	..
Larch, (*Larix Europea,*) ..	1·323	34	30-36	31-35	..	34	..	..
Elm, (*Ulmus Campestris,*) ..	1·250	36	33-37	34	..	34-36	..	48

Table No. 2.

Value of E ; *or Modulus of Elasticity, being that load which will produce a deflection of* 1 *inch, if applied at the centre of a beam,* 1 *foot long and* 1 *inch square, supported at both ends.*

	Adopted.	Barlow.	Rankine.	Roorkee Treatise.	Molesworth.	Stoney
Jarrah, ...	2700	..	2678	..	..	..
Johore teak, ...	..	..	..	..	..	..
Paloo, ...	4800	..	5625	3948	..	..
Iron-wood, (Ceylon,) ..	6000	..	5972	..	..	..
Satin wood, ...	5200	..	6250	4163	..	..
Sal, ...	4800	..	5042	4209-4963	..	..
Palmyra,..	5700	..	6505	4904	..	..
Babool, ...	4150	..	..	4111-4186	..	..
Halmilille, ...	3000	..	2245	3836	..	..
Iron-wood, (Burmah), ..	4300	..	..	4283	..	..
Teak, ...	5000	5563	4398-6481	3978	..	5589
Sissoo, ...	3800	..	..	3516-4022	..	..
Jack, ...	4100	..	4190	4030	..	..
Ash, ...	3600	3790	3333	..	3796	3807
Neem, ...	2900	..	..	2672-3183	..	..
Milille, ...	4700	..	4630-4722	..	..	..
Ebony, (Ceylon,) ..	3200	..	3248	..	..	..
Mee, ...	3700	..	4352	3174	..	..
Oak, (Himalayan,) ..	..	..	..	..	..	..
Poon, ...	3500	4077	..	2944	..	3911
Cheer, ...	4000	..	..	3672-4668	..	..
Birch, ...	3600	3600-3978	3427	..	..	3807
Mahogany, (Honduras,)	3100	..	2615	..	3694	3694
Cocoanut, ...	3600	..	..	3605	..	..
Oak, (British,)	3100	1863-4032	2500	..	3935	2022-3358
Mango, ...	3400	..	..	3120-3710	..	..
Chestnut, ...	2400	..	2375	..	..	..
Oak, (American red,) ..	4500	..	4479	..	..	..
Beech, ...	3100	3119	2812	..	3113	3133
Toon, ...	3100	..	..	2684-3568	..	..
Spruce fir, ...	3300	..	2917-3750	..	..	..
Deodar, ...	3500	..	..	3205-3925	..	..
Sycamore, ...	2100	..	2167	..	..	..
Memel, ...	3600	3479-3852	..	..	..	..
Oak, (Dantzic)	2700	2744	..	..	..	2757
Red pine, ...	3800	4240	3042-3958	..	4667	2778-4259
Cedar of Lebanon, ..	1000	1012	..	..	..	..
Larch, ...	2100	1419-2426	1875-2834	..	2486	1427-2437
Elm, ...	2000	1458-1950	1458-2792	..	3102	1620

y Modulus or Values of T . K_T *and* E . K_E .

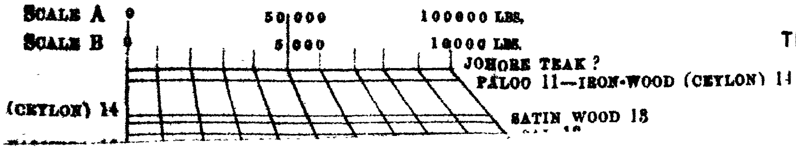
Na		$\frac{1}{13}$		$\frac{1}{12}$		$\frac{1}{11}$		$\frac{1}{10}$	
	E . K_E	T . K_T	E . K_E	T . K_T	E . K_E	T . K_T	E . K_E	T . K_T	E . K_E
Jarrah,	29·16	88·35	39·15	112·40	54·00	145·89	76·41	194·23	112·05
Johore te	..	84·65	..	107·70	..	139·79	..	186·11	..
Paloo,	51·84	82·53	69·60	105·00	96·00	**136·29**	**135·84**	181·44	199·20
Iron-woo	**34·80**	81·74	87·00	104·00	120·00	134·99	169·80	179·71	249·00
Satin wo	56·16	**74·67**	**75·40**	95·00	104·00	123·31	147·16	164·16	215·80
Sal,	51·84	**72·78**	**69·60**	92·60	96·00	120·19	135·84	160·01	199·20
Palmyra,	61·56	69·17	82·65	88·00	114·00	114·22	161·31	152·06	236·55
Babool,	44·82	69·17	60·18	88·00	83·00	**114·22**	**117·45**	152·06	172·23
Halmilill	32·40	66·34	43·50	84·40	60·00	109·55	84·90	145·84	124·50
Iron-woo	46·44	65·71	62·35	**83·60**	**86·00**	108·51	121·69	144·46	178·45
Teak,	54·00	62·88	72·50	80·00	100·00	103·84	141·50	138·24	207·50
Sissoo,	41·04	59·74	55·10	**76·00**	**76·00**	98·65	107·54	131·33	157·70
Jack,	44·28	**58·95**	**59·45**	75·00	82·00	97·35	116·03	129·60	170·15
Ash,	38·88	58·95	52·20	**75·00**	**72·00**	97·35	101·88	129·60	149·40
Neem,	31·32	57·85	42·05	73·60	58·00	95·53	82·07	127·18	120·35
Milille,	50·76	56·75	68·15	72·20	94·00	93·72	133·01	124·76	195·05
Ebony, (	34·56	56·75	46·40	72·20	64·00	**93·72**	**90·56**	124·76	132·80
Mee,	39·96	56·75	53·65	**72·20**	**74·00**	93·72	104·71	124·76	153·55
Oak, (Hi	..	52·66	..	67·00	..	86·97	..	115·78	..
Poon,	37·80	**50·30**	**50·75**	64·00	70·00	83·07	99·05	110·59	145·25
Cheer,	43·20	49·52	58·00	63·00	80·00	81·77	113·20	108·86	166·00
Birch,	**38·88**	49·52	52·20	63·00	72·00	81·77	101·88	108·86	149·40
Mahogar	33·48	48·34	44·95	**61·50**	**62·00**	79·83	87·73	106·27	128·65
Cocoanu	**38·88**	47·79	52·20	60·80	72·00	78·92	101·88	105·06	149·40
Oak, (B	33·48	47·79	44·95	**60·80**	**62·00**	78·92	87·73	105·06	128·65
Mango,	**36·72**	46·53	49·30	59·20	68·00	76·84	96·22	102·30	141·10
Chestnu	25·92	46·37	34·80	59·00	48·00	76·58	67·92	101·95	99·60
Oak, (A	48·60	45·27	65·25	57·60	90·00	74·76	127·35	99·53	186·75
Poplar,	..	44·80	..	57·00	..	73·99	..	98·50	..
Beech,	33·48	**44·80**	**44·95**	57·00	62·00	73·99	87·73	98·50	128·65
Toon,	33·48	**44·02**	**44·95**	56·00	62·00	72·69	87·73	96·77	128·65
Spruce	**35·64**	44·02	47·85	56·00	65·00	72·69	93·39	96·77	136·95
Deodar,	37·80	43·39	50·75	55·20	70·00	71·65	99·05	95·39	145·25
Sycamo	22·68	41·89	30·45	53·30	42·00	69·18	59·43	92·10	87·15
Memel,	38·88	39·30	52·20	50·00	72·00	64·90	101·88	86·40	149·40
Oak, (I	**29·16**	38·51	39·15	49·00	54·00	63·60	76·41	84·67	112·05
Red pi	41·04	35·37	55·10	45·00	76·00	58·41	107·54	77·76	157·70
Cedar c	10·80	35·37	14·50	45·00	20·00	58·41	28·30	77·76	41·50
Larch,	22·68	**31·44**	**30·45**	40·00	42·00	51·92	59·43	69·12	87·15
Elm,	21·60	**29·08**	**29·00**	37·00	40·00	48·03	56·60	63·94	83·00

lowest result.

is used for depths exceeding this limit, whilst the coefficient K_E

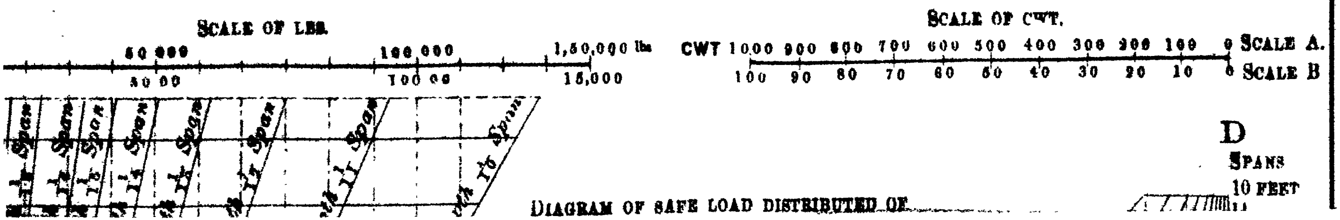
LE FOR LOADS OF BEAMS OF VARIOUS TIMBER; APPLICABLE TO DIAGRAMS FOR TEAK BEAMS.—PLATES XLVII. AND XLVIII.

The numbers which follow after each kind of timber, denote the limit of DEPTH OF BEAM to which the scale is applicable. The references on the right hand of the scale apply to the DIAGRAM OF TRANSVERSE STRENGTH, and can be used for depths EXCEEDING the limiting number; those on the left hand apply to the DIAGRAM OF STIFFNESS, to be used for depths less than the limiting number (the limiting number is the span ÷ depth, thus 14 denotes a depth of $\frac{1}{14}$th of the span, &c.)



TRANSVERSE STRENGTH.

NOTE.—Those timbers marked with an asterisk* have so low a modulus of elastici-


SCALE OF LBS.
50 000
100,000
1,50,000 lbs
5000
10000
15,000
SCALE OF CWT.
CWT 1000 900 800 700 600 500 400 300 200 100 0 SCALE A.
100 90 80 70 60 50 40 30 20 10 0 SCALE B
D
SPANS
10 FEET
Span
DIAGRAM OF SAFE LOAD DISTRIBUTED OF

DESCRIPTION OF A LIME KILN USED ON THE SUPPLY BRANCH, LOWER GANGES CANAL.

[*Vide* Plate LI.]

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THE kilns are meant to burn lime with firewood, and can be built to contain from 500 to 5,000 cubic feet of lime each.

The expenditure of fuel is from 1,150 cubic feet to 1,300 feet tolerably dry firewood per 1000 cubic feet of nodular kankar loaded, and lime can be turned out in from 4 to 5 days, including time required for loading.

The method of loading is as follows :—

The flues having been filled with *úpla* are covered over by dry bricks; about 18 inches deep of firewood is then laid horizontally over the floor with the length of logs radiating towards the centre of kiln, and closely packed. After this alternate layers of nodular kankar and wood, each 12 inches deep, are put in. In the centre of kiln a little pillar of *úpla* of about 1½ feet diameter is built up at the same time as the layers of kankar and firewood, and a row of single logs of wood is also laid vertically all round between kankar and side wall of kiln. The top of last layer of wood is flush with top of kiln, and the last layer of kankar appears above it, but as soon as firing has commenced it sinks rapidly.

All four flues are set on fire at once at their heads, and the fire passes on easily and quickly along the flues to the centre, where it lights the pillar of *úpla*, and communicates through it with all the successive layers of firewood.

As the kiln itself is built for the most part of sundried bricks, its original cost does not exceed Rs. 2 to 3 per 100 cubic feet of its capacity. The loading costs 8 annas per 100 cubic feet, and the outturn in lime is from 80 to 85 per cent. of kankar loaded, the balance being underburnt or bajri.

W. G.