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[SECOND SERIES.]

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MAJOR A. M. BRANDRETH, R.E.,

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EDITOR'S NOTICE.

I MUCH regret the scanty proportions of this Number, due of course to the falling off in the number of articles contributed, and hope that my drawer may be soon replenished, that the full quantity of matter may be made up to Subscribers in the next Number.

It would be a great pity if the Series came to an end, and I take this opportunity of calling on all old Subscribers and many new ones to step in to the rescue.

At the request of Captain Wilberforce Clarke, R.E., I have to draw attention to the fact that the conclusion in his Article No. CCLXXII., that the effect of brakes was greatest when the wheels were skidded, was the result of data furnished in the Report of the Royal Commissioners on Railway Accidents for 1877; but that now the more recent and exhaustive experiments, the results of which were recorded by Captain Galton, in a paper read before the Institution of Mechanical Engineers at Paris in June last, of course outweigh the former ones, and it appears that the popular notion of the retarding effect of brakes being greater when the wheels are just on the point of being skidded, than when they are actually skidded is correct.

A. M. B.

CONTENTS.

As no Loose Copies of the Professional Papers are now kept in Stock, Subscribers wishing extra copies of any separate Articles in the present Number, should make early application to the SUPERINTENDENT OF THE PRESS, so as to reach him before the type is broken up. The price of Loose Copies is reduced to one anna per 8 pages, or part of 8 pages, and half an anna a Plate, up to a maximum of eight annas; but requisitions can only be complied with if received before the type is broken up. To facilitate this, the following list of Articles received for publication is issued. It will not, it should be remarked, bind the Editor to issue all Articles entered in case more interesting matter is received.

The articles now in hand are—

1. The Improvement of Land in the Province of Mysore, and Irrigation from Tanks. By Major A. F. Fraser, R.E.

2. Translation of Report of a Commission of the French Academy of Science on a Memoir by M. Popoff, entitled new Researches on the expression of the conditions of motion of water in drain pipes. By Captain Allan Cunningham, R.E.

3. Stoney's Helical Excavator and Under-cutter.

Subscribers wishing to be supplied with Covers for Volume No. VII., are requested to send notice at once with price, i.e., Rs. 0-12-0.

A. M. B.

No. CCLXXXVII.

CANNING COLLEGE, LUCKNOW.

[*Vide* Plates I.—IV.]

BY J. A. WILLMORE, ESQ., C.E., *Exec. Engineer.*

THE Canning College, so named in honour of the late Lord Canning, was built at the expense of the Taluqdars of Oudh as a place of education for their sons and for the sons of other high class natives.

The foundation stone was laid on the 13th November 1867, by Sir John Lawrence, the then Governor-General, the usual coins &c. were placed in the stone which is situated under the floor of the tower on the west side of front portico. The design first accepted in 1866 was subsequently rejected and fresh designs invited; the design ultimately accepted and carried out was prepared by Tika Ram, Head Draftsman in the office of the Engineer-in-Chief, Rajputana State Railway, and was published with the proposed Specification in No. 22 of Vol. V. of the Roorkee Professional Papers on Indian Engineering for October 1876.

The architectural features of that design have been adhered to, but owing to the designer not having supplied detailed working drawings, and from other causes, very many alterations have been made in the construction, as the following short description of the finished building will show.

The accommodation provided consists of an Examination Hall 95′ × 45′, (the original length having been reduced by 5 feet to allow of the east end wall being thickened to act as an efficient abutment to the elliptical portion of the arched roof,) a Library 51½′ × 29′, and two rooms 24¾′ × 23½′ for the Principal and office; on the east of the Examination Hall, there are two rooms 22½′ × 24¾′ for Native Professors and Graduates, and two rooms 23′ × 24¾′ one for European Professors, the other for a class room; on the north side of the central corridor, there are seven class rooms, two 29⅓′ × 35½′, one 29′ 1″ × 35½′, and four 25′ 5¼″ × 35½′: there are also two corner rooms 11′ × 11′, and two 13′ × 13′, and two small octagonal rooms in the front towers.

Ground was first broken in October 1876, and the work entirely completed in November 1878.

The soil on which the building stands was found to consist of some two feet of rubbish, the remains of the former old buildings, and below that of sand; the foundations throughout the building are carried down to a depth of 8 feet, the lower 7 feet consists of concrete composed of 65 parts of brick ballast, 21 parts of surkhi and 14 parts of kankar lime; the lime for this and the whole of the work being burnt on the spot; the concrete after being thoroughly mixed on a platform was spread in 6 inch layers and rammed with ordinary iron rammers till quite hard. The upper one foot is of 1st class brickwork, this and the brickwork throughout the building, except in inner cross walls, where 2nd class bricks were used, is of 1st class bricks set in English bond, in mortar composed of equal parts of fresh kankar lime and surkhi.

The plinth is 4½ feet high, and inverts are given under the arches of the Examination Hall to equalize the pressure on the foundations; this provision was not made in the design. On the top of plinth a damp course of asphalte ⅝-inch thick was laid.

The superstructure, which with the exceptions hereafter mentioned, is entirely of brickwork, was carried up evenly throughout the whole building and kept thoroughly wet until completed.

The roofs of upper and lower verandahs and corridors are not made as in original design, but consist of segmental arches of 9 feet span and 2½ feet versine; the span of arch is made less than width of verandah by bringing the arch forward on to the cornice, the arches are 9 inches thick, and the spandrels up to level of extrados are filled in with concrete composed as for foundations, the thrust of the arch is taken by wrought-iron bars each 3″ × ⅝″ tied together at 8 feet intervals by bolts 1 inch diameter.

The roofs of Library and all rooms, except Examination Hall and turrets, are of brick arches turned between girders, the arches are 4½ inches thick at crown, and 9 inches at the haunches, the spandrels up to level of tops of girders are filled in with concrete composed as for foundations, and the whole of the outer roofs are covered with a layer of terrace having a good slope outwards; the finished thickness of terrace averages 4½ inches, and is composed of 4 parts brick ballast and coarse surkhi and 1 of fresh lime, these materials were thoroughly mixed and spread on the roof to the required thickness, then beaten till quite hard, a layer of fine mortar mixed with gur was then given, and the whole surface finished off by being well rubbed over with castor-oil.

The girders for these roofs are entirely of wrought-iron, and were made on the spot. For the Library and three largest class rooms they are 2 feet deep with webs ¼-inch thick and flanges of double 4″ × 4″ × ⅜″ L-irons; for other rooms they are 2 feet deep with webs ¼-inch thick and flanges of double 3″ × 3″ × ¼″ L-irons; for small porches they are 15 inches deep with ¼-inch webs and flanges of double 2″ × 2″ × ¼″ L-irons; the girders are designed so that the load on them induces a strain on the flanges of less than 5 tons per square inch of effective section; where necessary to withstand the thrust of end arches as in porches, &c., bars were built into the walls and secured to the nearest girder by iron bolts. The girders, bolts and all iron-work received two coats of paint before being fixed in position.

The Library roof in original design was arched, and caused a very unsightly projection in the line of front parapet. The alteration from a single arch, to arches between girders, while improving the appearance of the front elevation, necessitated some provision for lighting in place of the end circular lights; this is given by a sky-light 21¾′ × 6′ placed in the centre of the Library roof. To take the thrust of the roof arches at the ends of the space left for sky-light, strut girders are given between the four centre main girders with webs ¼-inch thick and flanges on one side only of 4″ × 4″ × ⅜″ L-iron, these are rivetted to main girders by L-irons 3½″ × 3½″ × ⅜″. Round the top of the rectangular space thus formed and bolted to the top flanges of girders is a sill of sal wood 8″ × 4″ into which the uprights of sky-light are fixed; the sides and ends of sky-light have glazed sashes working on pivots. The roof, which is curved, is covered with 1-inch planks tongued and grooved and painted with three coats of oil paint, and over this corrugated iron No. 18 BWG carried well out over ends and sides. The inside of sky-light and wells formed by main and strut girders are painted a dead white, and a very good light has been secured.

The roof of Examination Hall, which in original design is a segmental arch with elliptical ribs, has been made elliptical throughout, the span of plain portion being 45 feet and of ribs $43\frac{1}{2}$ feet; these latter are disposed in pairs immediately over Corinthian pilasters. The east end of roof which is elliptical in plan is domed to meet the straight portion. The whole of the arching springs at a height of $31\frac{1}{2}$ feet above floor level, and has a versine of 15 feet. The thickness of plain portions of roof is $14\frac{1}{2}$ inches at crown, increased to $22\frac{1}{2}$ inches at haunches; where the ribs occur these dimensions are increased by 9 inches.

The arch was built on a Hindustani centre supported by pillars of brick-in-mud placed about 8 feet apart, the exterior of centre was worked roughly to shape and finished with lime mortar, the true shape being obtained by use of templets made for the purpose; the arch was built in lengths of 15 feet, so that each joint comes between a pair of ribs. The whole roof was built and keyed in 15 days, being completed on the 23rd June 1878; there was some little delay in getting the backing up to the required height, and the centering was not wholly struck until the 1st August. Levels taken at 10 feet intervals along the top of arch just after keying up and after centres were wholly struck, showed the maximum settlement to be 0·1 foot and minimum 0·05 foot, the mean being $\frac{15}{16}$-inch. In the straight portion of the roof the thrust is taken by $4'' \times 4'' \times \frac{3}{8}''$ L-irons placed 6 feet above springing and connected by tie-rods $1\frac{3}{4}$-inch diameter placed $7\frac{1}{2}$ feet apart. The spandrels are filled with concrete as for foundations, and a 3 inch layer of terrace is given over the whole.

The floors throughout the building are of Mirzapore stone slabs $2' \times 2' \times 2''$ set in 2 inches of lime mortar over brick rubbish carefully rammed.

The central rectangular and corner turrets have Mirzapore stone pillars and lintels, the arches between the pillars are cut in 4-inch stones which are let 2 inches into both pillars and lintels; the joints are set in fine lime mortar, and the lintel stones are held firmly together by iron cramps run in with sulphur; the pillar bases and caps are secured by vertical iron dowels also run in with sulphur. The roofs and work above lintels is entirely of 1st class brickwork, in rectangular turret the roof is a semi-circular arch 14 inches thick, and the corner turrets are domed thrust bands of $4'' \times \frac{3}{8}''$ iron being built in at a height of $2\frac{1}{2}$ feet above springing; round these corner turrets there are projecting balconies supported on stone brackets 2 inches thick, these brackets project 4 feet and are built 2 feet into the wall; there is no weight on the portion built in except the stone flagging, so to prevent any chance of tilting an iron rod ¾-inch diameter was passed through them all at the centre of their depth, and at a distance of 1½ feet in from the face of the wall, this rod is embedded in brickwork which comes up flush with the tops of the brackets.

The two small turrets in front and the four minarets are entirely in 1st class brickwork.

The steps are of brickwork with treads of Mirzapore stone 2 inches thick.

The projecting windows in front corner towers are carried by brick corbels, and a capping sill of stone 6 inches thick cut to the shape of the window on the outside and carried through so as to be flush with inside face of wall.

The whole building inside and out, except the interior of Examination Hall, is plastered with a thin coat of sand plaster, composed of 1 part stone lime, 1 part kankar lime, and 2 parts clean Goomtee sand, ground together in a mortar-mill and laid on in the usual manner; all mouldings and ornamental work were executed in brickwork as closely as possible to the finished shape so as to reduce the thickness of plaster to a minimum.

The exterior of the building and interior of end and back verandahs and porches are left of the natural colour of the plaster, the ornamental work having a ground of pale neutral tint; the class and other rooms except Examination Hall, are coloured light blue, the roofs and cornices being white; the central corridor, lower front verandah and both upper verandahs are entirely white, so as to throw as much light as possible into the Examination Hall, which receives its light through them.

The Examination Hall is plastered throughout with white plaster polished to imitate marble, the rough coat is composed of equal parts of surkhi and fresh kankar lime, this is covered with a thin coat composed of white lime and powdered Jubbulpore soap-stone worked in and rubbed up to a fine polish.

The upper verandahs are reached by two spiral stair-cases formed in the east end wall of Examination Hall; they are 9 feet diameter with a newal 1½ feet diameter, giving a clear width of step of 3 feet 9 inches, centre width of tread is 1 foot 2½ inches, and rise 8 inches; the steps and rises are of Mirzapore stone, the former 4 inches thick with a moulded nosing, the latter 2 inches; the south stair-case is continued up to the roof of Examination Hall, its outlet being covered by an arched roof which is carried up spirally from a point 1½ feet below roof level, the stair-case door opens on to the roof behind the turret on the east side of front portico, which hides it from the front, while it is hidden from the east by the parapet which at this point is 4½ feet high.

The doors and windows throughout the building are of teak, fixed in teak chowkuts, these latter are not built into the walls, but fitted accurately to the openings in the brickwork and secured by screws to dove-tailed bricks of sal wood, which were after being soaked in tar built into the walls; in addition to the glazed or panel doors, all outer doorways are fitted with teak venetians.

The arches in room over front porch, and also the front doors of upper front verandah, are fitted with ornamental cast-iron railings with teak top and bottom rails.

Ventilation is provided in Examination Hall by holes left at the soffit of the arch between each pair of ribs; it is provided in a similar manner for the long verandahs and corridors, and in rooms by openings in the ends of roof arches, which are carried up the end walls; all openings are covered by suitable caps to prevent the entrance of rain.

Polished brass finials are given to turrets, minarets and the projecting windows of corner towers.

From the foregoing description it will be seen that the main alteration made from the designer's specification is, that there is now no woodwork in the whole building except the doors, chowkuts, and library sky-light, and these in no way affect the stability of the building, the durability of which is only limited by the life of the iron and bricks used; these were of the best kinds procurable, and every care was taken and everything that suggested itself during the construction of the work done to ensure the greatest strength and durability.

The general effect of the exterior is very poor. The style, as the designer stated, is in harmony with the surrounding buildings of the Kaiser Bagh, but these Ferguson long ago condemned in the strongest terms as "corrupt and degraded," and apart from the design the building is situated almost immediately in front of the Tomb of Nawab Saadut Ali Khan and close to that of his Begum Moorshed Zadi, and these two lofty buildings, the platforms of which are higher than the floor of the College, in such close proximity to it, have the effect of dwarfing its dimensions and rendering it insignificant; this was foreseen, but unfortunately the foundation stone had been laid and the Taluqdars objected to any other site.

The total cost of the building was Rs. 1,73,299, or Rs. 5 per square foot of plinth area, the details of the cost are given in the abstract attached.

The building was formally opened on the 15th November 1878, by Sir George Couper, Bart., Lieut.-Governor of the N.-W. Provinces and Chief Commissioner of Oudh, having been almost exactly two years in construction.

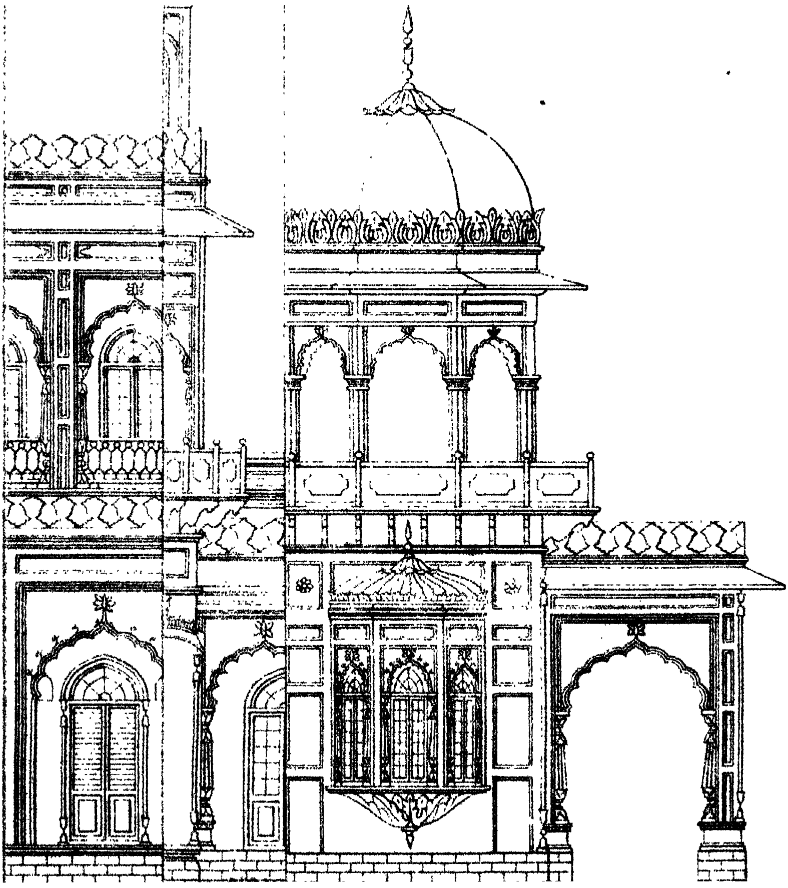
ABSTRACT.

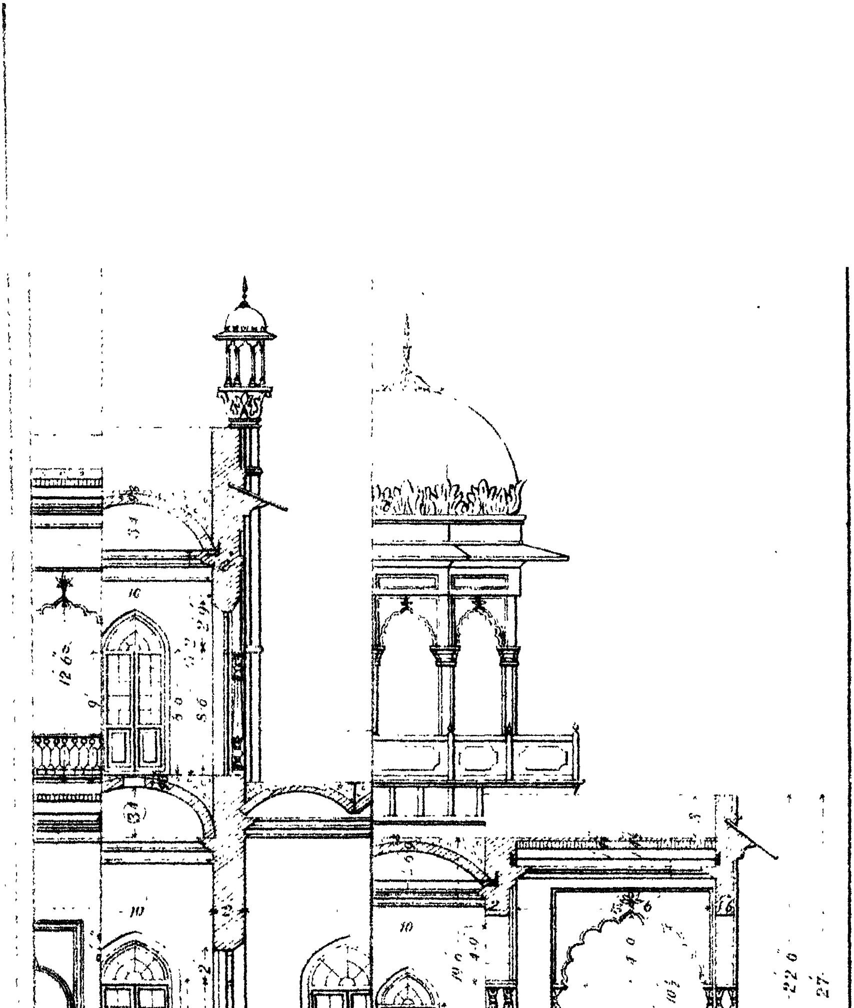
Quantity.	Item.	Rate.	Per.	Amount.
				RS.
c. ft.				
125,396	Earthwork, ...	3/-	°/oo c. ft.	376
45,119	"	2/8	"	113
174,752	Earth filling, ...	3/-	"	524
30,046	Dismantling old brickwork, ...	1/-	°/o "	300
97,720	Concrete in foundation, ...	10/-	"	15,635
9,896	Brick casing in clay, ...	12/-	"	1,188
11,197	Pakka brickwork in foundations, ..	24/-	"	2,687
37,317	" " plinth, ...	24/-	"	8,956
1,608	" " inverts, ...	26/-	"	418
Mds.				
5	Hoop iron for bonding	15/-	Md.	75
s. ft.				
8,653	Asphalte, ...	10/-	°/o s. ft.	865
c. ft.				
109,727	1st class brickwork in superstructure, ..	24/	" c. ft.	26,334
20,689	2nd " " " ..	21/-	"	4,334
177	1st " dismantled and rebuilt,	11/8	"	20
6,689	Arch brickwork, ...	26/-	"	1,739
1,134	" " 2nd class, ...	23/-	"	261
18,940	Roof arches, ...	26/-	"	4,924
9,688	Moulded brickwork, ...	35/-	"	3,391
9,796	Concrete in spandrels, ...	16/-	"	1,567
s. ft.				
29,941	Terrace roofing, ...	14-	°/o s. ft.	4,192
134,048	Sand plaster, ...	3/-	"	4,021
38,174	Moulded plaster, ...	6/8	"	2,481
16,797	Moulded and glazed plaster, ...	7/-	"	1,176
c. ft.				
90·83	Wooden bricks, ...	3/8	c. ft.	318
cwt. qrs. lbs.				
1,014-2-24	Iron girders, ...	21/-	cwt.	21,309
179-0- 0	" ties and back plates, ...	22/8/-	"	4,029
s. ft.				
31,903	Stone flooring, ...	35/-	°/o s. ft.	11,166
9,872	Cornice slabs,..	33/-	"	3,258
	Carried over, ..			1,25,657

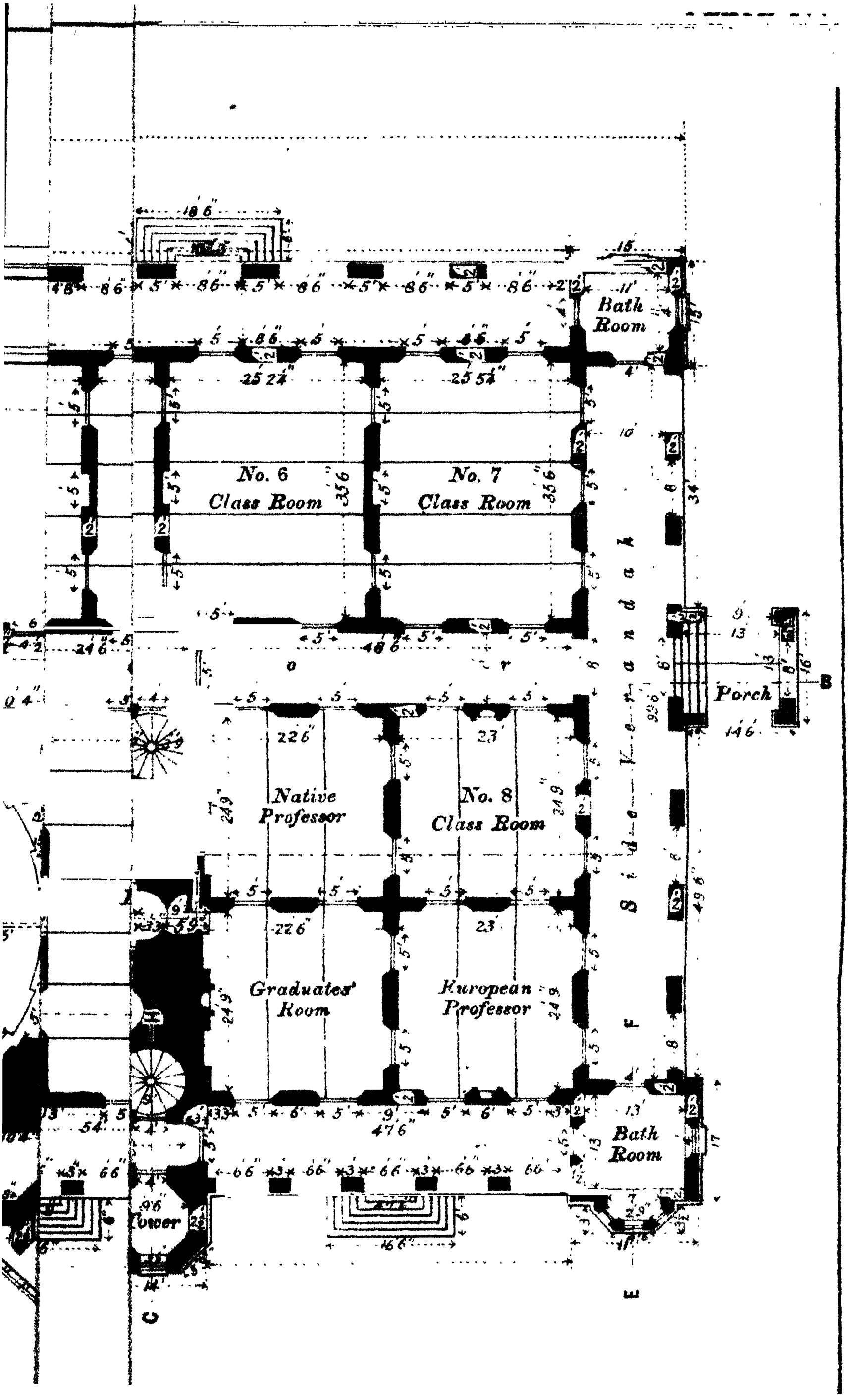
Quantity.	Item.	Rate.	Per.	Amount.
				RS.
	Brought forward, ..			1,25,657
c. ft.				
1,309½	Fair dressed ashlar, ...	3/-	c. ft.	3,929
467¾	Plain ashlar, ...	2/8	"	1,169
198	Moulded ashlar, ...	4/-	"	792
611·09	Teak chowkuts, ...	4/8	"	2,750
s. ft.				
5,681·58	1¾" doors and windows, ...	1/6	s. ft.	7,812
1,660	2" " "	1/8	"	2,491
2,449·97	2" Venetians, ...	1/6	"	3,369
32·76	Sky-light frame, ...	3/8	"	115
14·71	" planking, ...	4/8	"	66
116·80	" glazed windows, ...	1/4	"	146
s. ft.				
312	Corrugated iron, ...	..		144
30	Sheet zinc, ...	-/4/-	"	7
No.				
15	Polished brass finials, ...	30/-	each.	450
2	" " "	50/-	"	100
4	" " "	75/-	"	300
c. ft.				
58,016	1st class brickwork upper story, ...	26/-	°/₀ c. ft.	15,084
5,781	" " " arch-work, ...	27/-	"	1,561
12,889	" " " roof arches, ...	27/-	"	3,480
No.				
14	Venetians, ...	1/-	each.	14
c. ft.				
6,289	Concrete in spandrels, ...	16/-	°/₀ c. ft.	1,006
r. ft.				
75	Railings to Examination Hall, ...	1/10	foot.	122
s. ft.				
1,73,687	White and colour washing, ...	-/6/-	°/₀ s. ft.	651
cwt. qrs. lbs.				
21- 3- 20	Cast-iron rails and gratings, ...	22/8	cwt.	493
204	Painting, ...	3/-	°/₀ s. ft.	6
682	Concrete in steps, ...	16/-	"	109
c. ft.				
612	Moulded brickwork, ...	35/-	°/₀ c. ft.	214
35·72	Moulded ashlar, ...	4/-	"	143
678	Concrete in spandrels, ...	16/-	"	108
1,289	Arched roof brickwork, ...	26/-	"	335
45	" " " upper story, ..	27/-	"	12
	Petty items and contingencies, ...			649
	Total Rupees, ..			1,73,298

J. A. W.

PLATE I.







Bath Room
No. 6 Class Room
No. 7 Class Room
Native Professor
No. 8 Class Room
Graduates' Room
European Professor
Bath Room
Porch
Tower
Side Verandah

No. CCLXXXVIII.

INDIAN RAILWAY TRAFFIC,
No. 2.

By Col. J. G. Medley, R.E., *Consulting Engineer to Government for Guaranteed Railways, Lahore.*

In a paper on Indian Railway Traffic which I contributed to the Roorkee Professional Papers in the month of January 1876, I propounded various ideas on Indian Railway Traffic, some derived from my experience of American lines, others simply from general considerations such as naturally presented themselves to an outsider unconnected with Railway management.

Since that period, I have had nearly two years' experience of the practical working of the Indian Railway system, and it may be useful to record how far I have had to modify my ideas, or have succeeded in carrying them into practice, and what additional information on the subject I have derived from practical experience.

I. The first point to which I drew attention in the above paper was the importance of *low passenger fares* on Indian lines, and as further experience has fully confirmed this view, I cannot do better than summarize the reasons which have led me to this conclusion in the case of the 3rd class traffic, which forms more than $\frac{9}{10}$ths of the whole. Those reasons are briefly as follows :—

1. Because the value of money in India is at least six times as great as in England; or, what is the same thing, the people are six times as poor, so that the present rates, though low as compared with English standards, are in reality very high for India.
2. Because the numbers of people that still travel by road on foot are a strong proof of this.

3. Because passengers can be carried more cheaply than goods, and even at one pie per mile would pay better.*
4. Because as trains now run half empty, double the number of passengers could be carried for the same cost. But if the rates were halved, the increase in numbers would be very much greater than double, and a large profit would accrue on this increase.
5. Because the number carried per mile on the Punjab Northern State Railway being more than double the number carried on the East Indian Railway, the fares being nearly as 1 : 2, is a strong proof of this, especially when the population of the two provinces is compared.
6. Because the experience of other lines, both Indian and English, is conclusive in favour of very low fares.
7. Because the cost of haulage to the Railway is no concern of the passenger. If the passenger cannot be carried cheaply, he will not travel at all. If the Railway cannot carry below a certain rate at a profit, it should look for its total profit to the extra numbers carried, and not to increased rates.

With regard to 1st and 2nd class fares, I may here quote an extract from a note on this subject written last year:—

"I am certainly of opinion that the 1st class fares at present charged are too high in proportion to the 2nd class. The difference is so great that I *know* it practically drives a great many into the 2nd class (such as Officers in the Army) who would otherwise travel 1st.

* *Full Loads—at lowest rates.*

	Tons.
Tare weight of 3rd class carriage, ...	6·48
Fifty passengers, at 16 to the ton, ...	3·12
	9·60
	RS. A. P.
Receipts for one mile, at 1 pie, ...	0 4 2
	Tons.
Tare weight of a goods wagon, ...	6
Weight of load, ...	8
	14
	RS. A. P.
Receipts for one mile, at 5½ pies per ton, ...	0 3 8

Loads actually carried—at present rates.

	Tons.
Weight and load of 3rd class carriage as actually carried, ...	7·78
	RS. A. P.
Actual receipts for one mile, ...	0 4 1
	Tons.
Weight of goods wagon and load actually carried, ...	9·03
	RS. A. P.
Actual receipts for one mile, ...	0 2 8

"The present 1st class rate is *double* that charged on the Punjab Northern State Railway. I do not say it is *per se* too high a charge, the rate ($2\frac{1}{4}d.$ a mile) being about that charged on English Railways, while the value of money is only about one-half (*to the European*) what it is in England; that is, an Englishman out here ordinarily expends a rupee where he would expend a shilling in England. On the other hand, the average distances travelled are certainly more than double, I should say quite four times as long; and, if so, this would show that the State Railway rate is about fair.

"I do not think the 2nd class rate can be *raised;* there is a large and increasing '2nd class' European population in this country, with whom the value of money is practically about what it is in England, *i. e.*, with whom eight annas represent a shilling, and who certainly cannot afford to pay more than the present rate ($1\frac{1}{8}d$). Indeed with the longer average distance to be travelled, I am decidedly of opinion that a further reduction would lead to a considerable increase of traffic with this class.

"Taking everything into consideration, I think the difference between the 1st and 2nd class rates should be from 33 (for long distances) to 50 per cent. (for short distances) (instead of 100 per cent. all round as it now is), and, that the 2nd class rates should be reduced from nine pies to six pies per mile. This would make the 1st class rate eight to nine pies per mile.

"For the present at any rate, and as a step in the right direction, I would reduce the 1st class fares 50 per cent. (*i. e.*, from 18 to 12 pies), leaving the 2nd class unaltered."

These views have been so far accepted and acted upon by the Agent Scindo, Punjab and Delhi Railway, that the 1st class fares have now been reduced from 18 to 12 pies per mile—the 2nd class from 9 to 8 pies per mile—the 3rd class from $2\frac{1}{2}$ to $2\frac{1}{4}$ pies per mile.

The 1st and 2nd class reductions have only just come into force, and the results remain to be seen.

The slight reduction in the 3rd class resulted in the first half-year (after eliminating one abnormal month) in an increase of 170,000 in numbers, and of Rs. 24,000 in receipts, which is encouraging so far as it goes.

But no very striking result can be expected until a much more considerable reduction is made. At present rates I am still of opinion that we hardly touch the real 3rd class traffic of the country, which is too poor to travel largely at much above a one pie rate.* With that low rate, we should, I am convinced, fill our carriages and double the number of our trains, and should still (as the calculation given in the note above shows) earn more profit than we do with our cheap goods. Of the immense educational advantages to the people at large by thus accustoming them to travel, I refrain from writing.

II. The second point to which I drew attention in my former paper was the want of facilities for the convenience of passengers, among which I instanced as a principal one, *the trouble of procuring the ticket.*

This inconvenience I may perhaps have overrated, as it is not a serious one in the case of small stations, nor is it necessarily so at large stations, and even during rushes of traffic, with proper arrangements and organization. At Lahore, there are now three ticket windows opening into the 3rd class waiting halls; and in addition to these, 12 portable ticket boxes have been constructed which can be used outside the station, or at fairs, or wherever there are crowds waiting to take tickets. The difficulty is to persuade the ordinary Station Master to make full use of the extra conveniences provided. He has been so long accustomed to the sight of a pushing and struggling crowd, delayed for an hour at a single window, that he cannot understand the necessity of a more convenient arrangement.

There is, however, a wider principle involved in the simplification I before proposed in the matter of tickets, than the mere convenience to the passenger.

The widest application of that principle will be reached when all Railways (like roads) are the property of the State (*i. e.*, the public), and locomotion on them is *perfectly free*, the cost of construction, working and carriage† being met from the general revenues of the country. The same *principle* is now being recognized in the case of the Postal and Telegraph services of a country, which, it is now admitted, should not be expected to produce revenue, but that all surplus profits should be returned to the public in the shape of increased facilities or lower rates.

* The Passenger receipts on the Punjab Northern State Railway, 103 miles long (Lahore to Jhelum), for the half-year ending 30th June, 1877 were Rs. 64 per mile per week with a 3rd class fare of $1\frac{3}{4}$ pie. On the most profitable section of the Scinde, Punjab and Delhi Railway, 115 miles long (Lahore to Ludhiana), they were only Rs. 60, the 3rd class fare being $2\frac{1}{4}$ pies. The population of the towns on the latter section being *double* that on the former.

† Of course I do not forget that on common roads the traveller finds or pays for his own carriage, this difference (from the case of a Railway) does not, however, affect the *principle* involved.

No doubt the time has not yet arrived for acting on such a broad principle as this, but it is I believe sound, and should gradually be worked up to. An intermediate stage is clearly reached when the traveller is at any rate carried at *actual cost*, and as the cost per head diminishes as the number increases, it is evident that the rate might in time be almost nominal.

One step towards this is to simplify all arrangements connected with travel, both as tending to facilitate traffic and to lessen working expenses. And as, in the case of the Post Office, the same charge is made for carrying a letter 10 as 100 miles, so there should be greater simplification of the Railway ticket system, so as to give additional inducements for travelling the longer distances, increased *numbers* being booked to re-coup the difference. A passenger who only travels 10 miles on a Railway is evidently a much less profitable customer than one who travels 100 miles, if only because he costs just as much to book. A little consideration will show in fact that the mileage rate should be reduced according to the increased distance travelled. This is, in fact, the same principle that is pursued by a tradesman who gives a larger discount in the case of a larger purchase, simply because the large purchaser is more profitable to him than the smaller.

I would, therefore, invite attention to the subject of a much greater simplification and re-arrangement of passenger fares, so as to give additional inducements to the more profitable customers of a line.

III. Another inconvenience to which my former paper directed attention was the present cumbrous and vexatious *system of booking and weighing luggage.* I have hitherto endeavoured in vain to persuade the Railway authorities to try a simpler and less complicated system. I hope, however, shortly to be able to make the experiment on one of the State lines by the courtesy of the Director; and for the benefit of those willing to try a new system elsewhere, I subjoin the rules I have proposed for the line in question.

New Rules for Passenger's Luggage, Punjab Northern State Railway.

On and after the ________________ the following Rules regarding Passenger's Luggage will come into force for all *local* bookings on the above Railway.

The object is to do away with the present inconvenient and vexatious system of booking and weighing, and it is hoped that passengers will *assist the Railway officials in the present attempt to introduce a simpler* and more convenient arrangement.

1. All free luggage will be abolished, excepting such small articles as the passenger takes into the carriage with him, for the safety of which *he* is responsible.

2. All booking and weighing will be abolished, luggage being charged for by the *piece.*

3. A single piece of luggage will be an ordinary portmanteau, box or other article which can be carried by an ordinary coolie.

4. Heavy boxes or other pieces requiring two men to carry them will be charged as double pieces.

5. Any packages requiring more than two men to carry them must be weighed and booked as heretofore. [The public will therefore see the advantage of travelling with packages of reasonable size, or sending heavy pieces by Goods' Train.]

6. The Railway officials will be liberal in estimating pieces as single or double. In case of dispute, however, the decision of the Luggage Clerk must be accepted at the time, but the passenger can, if he pleases, insist on his luggage being weighed at the end of the journey, when the piece will be taken to be one maund.

7. On each piece of luggage as above, a printed label or ticket will be affixed by the Luggage Clerk; each label will bear a separate number and will have the names of the stations from and to which the piece is to be carried, and the charge for such carriage, printed thereon.

8. A duplicate of this label or ticket will be handed to the passenger who will receive his luggage on arrival at its destination, on giving up his duplicates to the Guard of the train.

9. If the duplicates are lost, the luggage will only be given up on a proper description being furnished, and a certificate of indemnity being signed.

10. Two, three or more small articles may be strapped or fastened together so as to constitute one piece; but if one ticket only is taken for the lot, the Railway is only responsible for the article on which the ticket is affixed, and it will rest with the passenger to see that the articles are securely fastened together.

11. All single pieces of luggage carried between Lahore and Wuzeerabad, or between Wuzeerabad and Jhelum, or between Goojranwalla and Goojerat, will be charged for at the same, or a single, rate.

12. All pieces carried beyond these limits will be charged at a double rate.

13. The following coloured tickets will therefore be used:—

Single pieces carried single distances, *i.e.*, between Lahore and Wuzeerabad, or Wuzeerabad and Jhelum, or Goojranwalla and Goojerat,	White,	4 as.
Double pieces ditto ditto, ...	Yellow,	8 as.
Single pieces carried double distances, *i. e.*, between Lahore and Jhelum, or Lahore and Goojerat, ...	Blue,	8 as.
Double ditto ditto, ...	Red,	1 Re.

*** By using two single tickets for a double piece, the number of kinds of tickets may be reduced from 4 to 2.

If found inconvenient in practice, the distinction between single and double pieces may be done away with, all pieces up to the maximum weight or size being treated as single.

IV. Another improvement obviously required to facilitate Goods' Traffic I pointed out to be the *establishment of Booking Offices*, in all towns within reach of the line, where goods can be received or delivered as at the Railway Station. This has been done to a small extent on the Scinde, Punjab and Delhi Railway, the carting to and from the line being done by contract at a small additional charge. The system should, however, be greatly extended, so as to include at least every important town within 50 miles of the line, especially if connected with it by a metalled road.

V. Another point noticed in my former paper was the *superior convenience of the American form of carriage* over the present designs for 3rd class carriages now in use. After considerable correspondence and discussion, an improved pattern carriage has been constructed in the Lahore shops, with *end* doors and platforms, and a central passage 2 feet wide, the passengers being seated two and two on each side. This carriage has the following advantages over those ordinarily in use:—

1st. It is the only pattern which admits of a urinal being provided, accessible to every passenger and yet offensive to none.

2nd. It is perfectly ventilated from end to end.

3rd. It enables the passengers to move about freely and even to stand outside.

4th. It enables a brake to be fitted and worked on either or both platforms, if required.

5th. In a train of such carriages, it enables the Guard to pass freely from end to end of the train, to give information or help, check tickets or prevent disorder.

As it only holds 38 passengers, instead of 50, for the same length of frame and at the same cost, it is of course more expensive; but as the present carriages do not, on the average, run more than half full, this is of less consequence, while the increased comfort and convenience to the passenger is, it is submitted, well worth the additional cost.

The new carriage has been specially adapted as a Troop or Ambulance carriage, the whole of the seats being made removable, and additional side doors being provided to admit doolies when required.

So far I have confined myself to the points already enumerated in my former paper. As regards other points, to which experience has forcibly directed my attention, I may mention:—

VI. The *immense importance of the Local traffic* of a line as compared with the through traffic—to exemplify this, I give an extract from a Note on the above subject as regards the Scinde, Punjab and Delhi Railway.

"I have obtained from the Auditor the figures below, showing the local passenger traffic during the half-year ending 30th June 1877, on the different sections of the line.

Sections.	Number of Passengers 3rd Class.	Number per mile in the half-year.
Lahore and Amritsar, 32 miles, ...	263,207	8,225
Amritsar and Ludhiana, 84 miles, ...	156,830	1,867
Ludhiana and Umballa, 66 miles, ...	100,241	1,519
Umballa and Saharanpur, 55 miles, ...	117,871	2,143
Saharanpur and Meerut, 71 miles, ...	82,878	1,167
Meerut and Delhi, 40 miles, ...	101,770	2,544
Lahore and Montgomery, ...	155,338	709
Montgomery and Mooltan, ...		
Mooltan and Sher Shah, ...		
Total 567 miles, ...	978,135	1,725

"The number of passengers booked from and to Foreign lines during the same period was 22,713.

"As the *total* number of passengers carried on the line during the half-year was 1,260,611, it follows that 1,137,898, or 98 per cent., were due to local traffic, of which 978,135, as above shown, were carried between the different sections as above, the remainder being carried from one section to another.

"Nothing can show in a more striking manner the importance of the local, as compared with the through, passenger traffic, which is further confirmed by the fact of the average distance travelled by a 3rd class passenger being about 50 miles."

VII. One obviously desirable measure in consequence of these facts is the *establishment of numerous Stations* at short distances apart, so as to pick up travellers at their own doors. In a populous country like the North-Western Provinces, I think the average distance between stations should not exceed 5 miles. 16 new stations have been thus established on this line within the last 18 months, with great advantage to the traffic and of course increased convenience to the public.

VIII. Another obvious deduction from the magnitude of the local traffic and the comparatively short distance travelled by the average passenger is the establishment of *convenient morning and evening Local Trains* between all large towns on the line, giving the country people the opportunity of attending fairs, markets and courts, and returning to their homes the same day.

This improvement has also been carried out to a considerable extent on the Punjab and Delhi Railway, the line from Lahore to Delhi (350 miles long) being broken up into six sections, of which four are thus conveniently served. These short passenger trains are combined with Goods' trains, and so far promise fairly; cheaper fares are however required to develope them thoroughly, and day or season tickets; also greater punctuality of running.

IX. To facilitate the development of the lucrative passenger traffic, due attention to the comfort of passengers is now recognized as desirable. *Convenient Waiting Sheds for 3rd class passengers* have now been provided at most stations, and are highly appreciated, in spite of the re-iterated assurances that natives *preferred* to wait outside under trees (which were never planted), especially on a cold, rainy, winter night!

The barbarous custom is, however, still in force of locking up carriages, and so preventing free egress at stations to comply with natural wants, which the present faulty design of carriages renders necessary. In this as in other instances, the idea is still prevalent that all Railway passengers should be treated as rogues or children, and the fact appears to be ignored that if the general business of life were conducted on such principles, it would soon come to a stand still altogether.

X. A very necessary improvement is now being carried out to facilitate Goods' traffic, and that is the provision of *proper shelter over the Goods platforms.* The small brick buildings first erected have been found totally inadequate for the purpose, and it is lamentable to see the utter want of protection from the weather in the case of the large quantity of perishable goods brought to the stations. As the Railway gave no receipt for these until deposited in the wagons, the line suffered no *direct* loss, and so nothing was done; it appears to have been overlooked how great was the *indirect* loss owing to the injury done to trade, and that a Railway, like a shop, *must* suffer with its customers. Large open corrugated iron sheds are now being erected at all stations, enough to shelter goods for two or three days. These will doubtless be followed by the erection of warehouses, at the expense of private parties or companies, and nothing will so much tend to steady the violent fluctuations of traffic.

XI. This line, like all others in India, has suffered for some time from a *want of sufficient Rolling Stock* for its goods traffic, and at the present moment of writing thousands of rupees are thus daily lost to the Railway in consequence. It may, in this as in other matters, be pointed out that no policy is so short-sighted and foolish as to make a railway and then to grudge the necessary means and appliances for making it *pay.* A railway is necessarily a very expensive thing both to construct and to work. If economy is the first thing to be considered, don't make it at all, but once having made it, it is *not* economy, but reckless extravagance, to *starve* it. Everything that can possibly tend to facilitate traffic, both in goods and passengers, should be freely and even lavishly provided, and it is only by working on such broad principles that a fair return can be hoped for. Establishment must not be grudged, the Managers of the line and heads of Departments should be freely trusted and liberally dealt with; but in return they should be *bound* to show good results, and it should be clearly explained to them that their own prospects, as well as reputation, will be identified with the success of the line.

It is to be borne in mind that the principles of Indian Railway management have been left to determine themselves in a very hap-hazard sort of way. Such important questions as the proper fares and rates to be charged, the true principles of classification of goods, the interchange of rolling stock, the proportions of dead to paying freight, the relative cost of high and low speeds, the comparative value of goods and passenger traffic, of through and local traffic, and numerous other questions of equal importance, on the right solution of which the financial success of every Railway is largely dependent, may all be said to be *open* questions, which have hitherto been determined simply by "rule of thumb." Of the Railway officials who have been brought out from England to work the lines, many no doubt have been able men; but it is no discredit to the Indian majority to say that they were scarcely fitted to investigate questions like the above, while many of them were only fit for working on in the groove to which they had always been habituated, and were incapable, from want of education, of applying their English experience to a totally different country and people.

Hence it has doubtless arisen that suggestions in the way of change and improvement have generally come from Government, and have, as a rule, been only carried into effect after considerable opposition on the part of the Railways, which are rather disposed to resent the interference of "non-practical" men.

The Guaranteed Railway system by which the Government is as deeply concerned in the prosperity of a line as the Shareholders, naturally gives great weight to all recommendations coming from the Government officers, but still such recommendations can only take the form of advice or suggestion. It remains for the Railway, as a rule, to take the initiative in all questions of improvement.

In justice it must be admitted, however, that even where the Government have had a clear field before them, as in the case of the State Railways, where they were not embarrassed by any "double Government," the policy pursued has not been so far in advance of the Guaranteed Companies as could be desired. Rates and fares have certainly been lowered, the classification of goods has been simplified, and less money has been wasted. But on some of the State lines, the worst faults of the older lines have been perpetuated. The stations have been designed without shelter for passengers or goods, the carriages have been copied from the old faulty patterns, and there has been a serious deficiency of rolling stock, and a general inability to appreciate and provide for the inevitable expansion of traffic.

These notes may perhaps be useful in directing attention to a few important points, but still more to the necessity of discussing all such points on broad, general principles, by which alone safe rules for future guidance can be arrived at. Without this, what is called "practical experience" is perpetually apt to degenerate into a mere following out of routine, and to obstruct, instead of assisting, improvement.

The proposed Railway Conference ought to be most valuable in helping to settle on true-principles some at any rate of those questions which I have indicated as open ones—they are however so numerous and "large" that little more than a beginning can be made in one Conference. But much will be done if the example can be set of looking to principle as well as practice in determining doubtful points—above all, if it is clearly kept in view that the true interests of the Railways, the Government and the public are really identical and not conflicting. If this is borne in mind, it will be felt that the discussion of all questions affecting this joint interest should be treated in an elevated manner, and should be as far as possible removed from the tone of a parish vestry.

J. G. M.

LAHORE,
January 10th, 1879.

No. CCLXXXIX.

EXPERIMENTS MADE AT NARORA, LOWER GANGES CANAL, ON THE STRENGTH OF DIFFERENT THICKNESS OF MORTAR JOINTS.

[*Vide* Plate.]

By Lieut. E. W. Creswell, R.E.

Different thickness of mortar joints to be tested were $\frac{1}{16}''$, $\frac{1}{8}''$, $\frac{1}{4}''$, $\frac{1}{2}''$, $\frac{3}{4}''$. A level site close to the weir sluices was selected (as the blocks of brickwork were afterwards to be put into the talus of that work), and five rows of brickwork bars built, $15' \times 2\frac{1}{2}' \times 2\frac{1}{2}'$, each row containing ten bars, and were numbered A to E.

Mortar joints in row A were all $\frac{1}{16}''$, in row B $\frac{1}{8}''$, and so on, in order mentioned above, row E being $\frac{3}{4}''$.

The foundations for these bars were made one foot deep, *see* plan. The centre 10 foot portion of the foundations being of bricks laid in mud, the end 2 feet 6 inch portions of bricks laid in mortar, a thin layer of mud was spread over the whole surface of top of foundation, so that there might be no adhesion whatever between the superstructure and the foundations.

The bricks were sand-moulded kiln burnt, were carefully gauged and sorted, so that each bar might be built with the required joint and still the total dimensions of bar as directed be attained.

The mortar used was two parts steam ground coal burnt kankar lime to one part sand, mixed with water in a country bullock 'chakki.'

The joints in every direction were carefully kept of the required thickness, and English bond employed.

The bars were all completed in August 1877.

In May and June 1878 the brickwork of the central 10 feet portion of the foundation was removed, and the bars were now simply supported at both ends by the 2 feet 6 inch pillars.

In order to break the bars, two stone slabs $2'\ 6'' \times 6'' \times 6''$ were placed one foot apart on top of the brickwork (as shown in *Figs.* 1 and 3) and equidistant from the centre of the bar. Across these 24 feet rails were laid, and over these other rails, till the load caused the bar to break across.

The line of rupture varied, but was always somewhere between the slabs of stone, and generally as line shown in *Fig.* 3.

It will be observed that the average breaking weight required was greatest in the row C, or of bars with $\frac{1}{4}''$ joint, this average diminishes slightly for the $\frac{1}{8}''$, and was less again for the $\frac{1}{16}''$ joint.

The thick joints $\frac{1}{2}''$ and $\frac{3}{4}''$ gave very poor results, average breaking weight being about $\frac{2}{3}$rd of that for the $\frac{1}{4}''$ joint.

The bar that gave the highest result was No. 4 B of the $\frac{1}{8}''$ joint.

The general result appears to be that $\frac{1}{4}''$ joint makes the strongest work, and should be employed in preference to the finer joints.

Table II. gives the values of the modulus of rupture per square inch of section for

(i) Average breaking weight of each row.
(ii) ,, ,, strongest bar ,,
(iii) ,, ,, weakest ,,

In all these cases the beam being supported at both ends and loaded with an even number of equal loads symmetrically placed on each side of the centre (as half the breaking weight may be considered as applied at the centre of each stone slab).

Neglecting weight of beam

(i) M = Moment of flexure = $2\,Wd$,
W = weight of each load
= $\frac{1}{2}$ breaking weight.
d = distance from point of support to application of load
= 4·25 feet.

(ii) $$M = \frac{f_0\, bd^2}{6}$$
$b = 30''$,
$d = 30''$.

(iii) From (i) and (ii) $$f_0 = \frac{2\,wd \times 6}{bd^2} = \frac{2\,w \times 4{\cdot}25 \times 12 \times 6}{30 \times 30^2}$$
$$= {\cdot}0113\,(2W).$$

Substituting for 2W the weights as given in Table I, values f_0 are found.

If the weight of the beam be taken into account, the modulus of rupture due to weight of beam, should be added. As all the bars were similar, this modulus will be a constant quantity.

$$M = \frac{W_1 L}{8} \begin{cases} W = \text{weight of bar,} \\ L = \text{length of bar.} \end{cases}$$

A cubic foot of this brickwork weighing 122·7 lbs.

$$W_1 = 122{\cdot}7 \times 10 \times 2\tfrac{1}{2} \times 2\tfrac{1}{2}$$

$$L = 10$$

$$\therefore M = \frac{122.7 \times 10 \times 2\frac{1}{2} \times 2\frac{1}{2} \times 10}{8}$$

$$M = \frac{f_0 b d^2}{6}$$

$$\therefore f_0 = \frac{122{\cdot}7 \times 10 \times 2\frac{1}{2} \times 2\frac{1}{2} \times 10 \times 12 \times 6}{30 \times 30 \times 30}$$

$$= 25{\cdot}56 \text{ lbs. per square inch.}$$

TABLE I.

Numbers.	$\frac{1}{16}''$ A	$\frac{1}{8}''$ B	$\frac{1}{4}''$ C	$\frac{1}{2}''$ D	$\frac{3}{4}''$ E	Remarks.
1	14,793	16,526	16,533	12,633	8,223	
2	12,375	16,538	17,296	10,194	9,410	
3	18,951	13,323	15,287	13,666	13,079	
4	18,460	22,391	20,056	12,872	10,672	
5	16,555	19,466	17,457	10,409	10,659	
6	14,337	20,790	16,086	15,800	12,366	
7	14,064	16,034	20,770	13,350	10,180	
8	14,560	14,332	18,955	11,150	12,348	
9	16,307	15,298	19,692	8,707	11,665	
10	14,615	19,701	19,729	8,235	11,625	
Total, ..	1,55,017	1,74,399	1,81,861	1,17,016	1,10,227	
Average, ..	15,501·7	17,439·9	18,186·1	11,701·6	11,022·7	

Table II.

lbs. per square in.; values of f_0 in Equation (iii).

	1/16″	1/8″	1/4″	1/2″	3/4″	Remarks.
	A	B	C	D	E	
Maximum, ..	215·	254·	235·	179·	148·	
Minimum, ..	140·	151·	182·	93·	93·	
Average, ..	176·	198·	206·	133·	125·	

Table III.

	1/16″	1/8″	1/4″	1/2″	3/4″	Remarks.
	A	B	C	D	E	
Maximum, ..	240	279	261	205	174	
Minimum, ..	167	177	208	119	119	
Average, ..	201	223	232	158	150	

E. W. C.

SHENGTH OF RELATIVE THICKNESS OF MORTAR JOINTS.

Scale. 1 inch = 4 feet.

Fig. 1.

PLAN

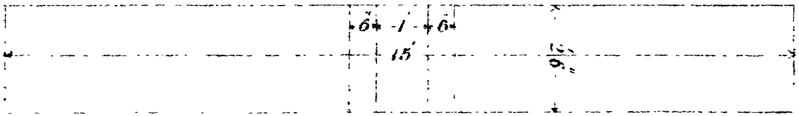


Fig. 2.

LONGITUDINAL SECTION

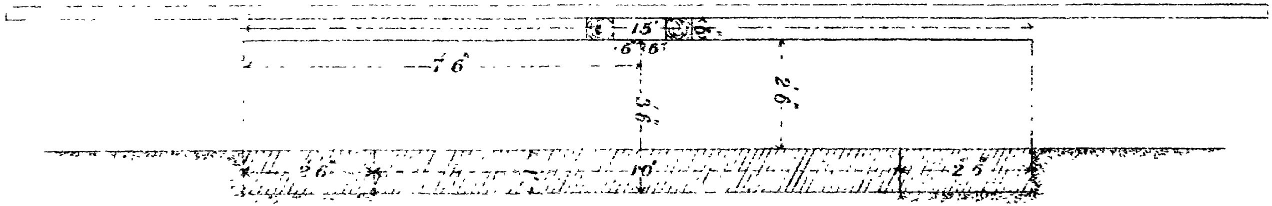
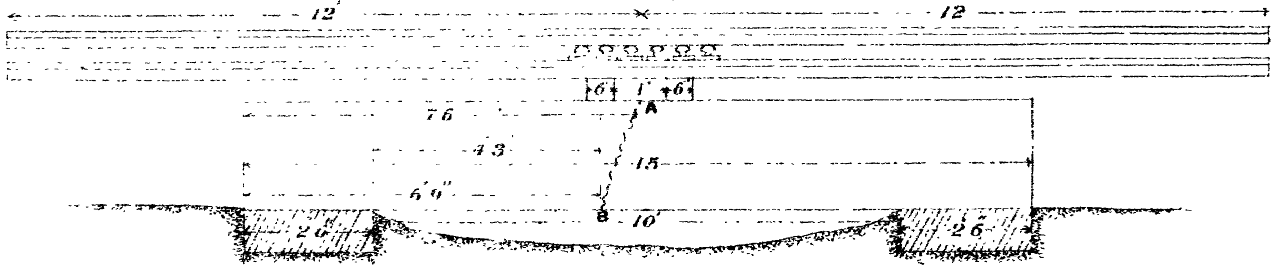


Fig 3.



No. CCXC.

ESSAY ON THE THEORY OF RUNNING WATER.

By J. Boussinesq, Paris, 1877.

Report on the above by a Commission of the French Academy of Science. Translated by Capt. Allan Cunningham, R.E., *Hony. Fell. of King's Coll. London.*

Translator's preface. The original Edition of this important work was published in 1872: the present (2nd) Edition was published, with considerable additions, in 1877. As it contains a consistent *rational* Theory of the flow of water, probably the best yet developed, and has stood the test of criticism for some years, it has been thought that the Report of the Commissioners of the French Academy of Science on the original edition (1872) containing a commentary on the whole work, might still be presented with advantage in an English translation to the large body of Engineers interested in Hydraulic Science.

1. An early exposition of the subject of this great work was the aim of a Paper read before the Academy on the 15th April, 1872, with the title:—"On the influence of centrifugal forces on the flow of water in prismatic channels of great breadth." The equations of varying steady motion of water in stream-lines, supposed originally sensibly straight, were therein established on a rational basis investigated in recent Notes; the author next calculated the effects of the centrifugal forces in those places where the fluid surface, and therefore also the stream-lines themselves presented a decided vertical curvature. He applied the Results to the study of waves and of other circumstances accompanying the passage from uniform to variable motion, and *vice versâ:* this led him to a primary classification of water-courses into Rivers and Torrents of two kinds.

The new Edition comprises the cases of both pipes and canals; it embraces fluid sections of various shapes, chiefly rectangles of great breadth, either constant or slowly varying, and circles or half circles, the latter being considered to present the second of the pair of in a certain sense, extreme cases between which all other figures of cross-section may be interpolated—at any rate for the computation of certain "coefficients"—by a sort of approximation quite sufficient for practical calculations. The author here treats the cases in which the bed of the channel has a sensible curvature, or is even wavy lengthways, like the water surface.

Considerations are then proposed which make the results of the application of Borda's Theorem on loss of *vis viva*, and of the expression for an "afflux" (ressaut) of water agree better with facts. Lastly, he treats at some length of non-permanent motion such as occurs in rivers in time of flood, and in the part of their course affected by tides; and by integrating these equations for slight degrees of non-permanence, he discovers laws which agree with experiment on the propagation of waves and swells on the surface, due regard being paid to the slopes, friction, and curvature which could have any effect on this propagation.

2. The problems of such variable motion as most commonly occurs in running water are in fact those which hydraulicians should now-a-days attempt. The empirical formulæ which have been constructed to express the relation between the quantity discharged, the cross-section, and the slope; or, which amounts to the same thing, between the rate of discharge, and the mean friction of the water on the envelope within which it flows are applicable only to uniform motion. For the case of unsteady motion, in which the relations between the velocities at any one spot have different values, it is absolutely necessary to consider in detail the velocities of the individual stream-lines; and, as a necessary consequence, the intensity of their mutual lateral action, styled internal fluid friction, must also be found.

The question of calculation of this fluid friction between stream-lines or -layers has long been,—as we have elsewhere had to say,—a real enigma, the solution of which was being ill, and therefore vainly, sought. The molecular motion was supposed to be continuous and regular, and it was hoped that the intensity of the mutual friction of the stream-lines depended only on their relative velocity, although numerous facts were tending to show that it depended also on the absolute dimensions of the cross-section; and—which is still more remarkable—on the absolute velocities. The author of the memoir now under review has been able to reconcile all this, and has given expressions for fluid friction-intensity, which agree with various experiments, by drawing a distinction between motion quite regular, continuous and simple, such as must take place in flowing through very fine smooth tubes, and motion which is whirling and tumultuous, such as is inevitably produced (as already shown by him in 1868) in spaces of a certain transverse extension, spaces in which continuous and regular variation is observable only in the *local mean velocities* (*vitesses moyennes locales*) which—neglecting rotation and oscillation—determine at each spot the *translation* of the molecules or the *flow* of the fluid. In these spaces, considering the abrupt changes in magnitude of the real velocities from point to point, the mutual friction between the fluid layers is of a kind quite different to that in capillary spaces. Its *coefficient*, *viz.*, that by which the difference between the local velocities of translation of successive stream-lines must be multiplied to obtain its intensity, is enormously greater than in tubes of less than a millimètre in diameter, in which the late Poiseuille made his experiments. Instead of being constant it depends at each spot, as Mr. Boussinesq has explained, on the *intensity of the whirling action*, and on the considerable loss or change of *vis viva* which it involves. It may vary from one to one hundred times or more, according to the transverse dimensions of the space in which the whirls have the chance of being formed, according to the velocity against the margins where they arise, and even according to the shape of the contour of the section and the distances from that contour, in starting out from which the whirls tend sometimes to converge, sometimes to diverge in their propagation into other parts of the same space.

3. After a preamble containing a succinct résumé of his memoir, the author shows first (§ i, ii,) that the equations of motion of hydrodynamics may be used for those velocities just styled "local mean velocities," about which the real molecular velocities oscillate with a sort of periodicity at each point; and that to obtain the internal actions, also "local mean," which are developed at these points, the six formulæ of the components of the forces both normal and tangential of Poisson, Cauchy, and Navier, may be formed between their differentials; provided that the coefficient of internal friction (ϵ), which therein multiplies the velocities of translation, as well as the differences between those of expansion by pairs be considered *variable* from point to point.

Then (§ iii) making some plausible and well reasoned hypotheses as to the intensity of the whirling action about which various facts agree in furnishing evidence, he assumes for this coefficient ε expressions, whereof one for the case of very wide rectangular channels or pipes is proportional both to the full depth, and to the bed-velocity, and the other for the case of circular or half-circular sections is proportional to the radius, to the marginal velocity, and also to the ratio of the radius to the distance of each point from the centre to which point the whirls tend as it were to become more intense before their final *destruction* (as Leonardo da Vinci puts it) or resolution into heat-vibrations.

These hypotheses are justified by the case first of the equation of motion which is uniform, or in wholly parallel stream-lines; for there result for the individual velocities at different distances from the free surface in the first case, and from the centre in the second case, laws represented by parabolæ of the second and third degrees respectively: which, as well as other results of the investigation, agree with the hydrometric experiments of Darcy, Bazin, Boileau, &c., properly discussed.

It is indeed from this, and from the mean results of experiments on discharge of streams, that Mr. Boussinesq deduces the approximate or mean values ·0006386 and ·0008094 to be assigned to two particular quantities; one, (A) entering into his two formulæ for internal friction, the other (B) by which he multiplies the square of the velocity u_0 against the sides of the channel, to obtain at each point thereof the frictional retardation which they exert per square unit divided by the weight of a cubic unit of the fluid. These two quantities vary besides with the degree of rugosity of the soil, and also—especially the second—slightly with the mean radius of the cross section, as well as with u_0 itself.

4. Furnished with the expressions so formed of the two kinds of friction, the author is enabled to enter on the investigation of an equation for the problem of variable steady motion.

It is known that a solution of this important problem was proposed in 1828 by Bélanger and Poncelet, who—for a stream contained in a prismatic channel—introduced into the equation of motion a term expressing the inertia brought into play by the change of mean velocity from section to section. Vauthier in 1836 rendered this solution applicable to a channel of any shape; and in the same year Coriolis modified it, remarking that in the terms which arises from the inertia or from the change of magnitude of the *vis viva* of the fluid sections, we ought, in consequence of the inequality of the velocities of these different stream-lines, to apply to the square of the mean velocity a coefficient styled a, a little greater than 1, which measures the mean ratio of the cubes of the individual velocities to the cube of that mean.

Almost every one since then formed the equation in Coriolis' mode by the principle of *vis viva, viz.*, by assuming either explicitly or implicitly that the frictions, both internal and external, have in each section the same intensity which they would have in uniform motion for the same sections, and the same mean velocity through each, so that the sum total of their work can be found by multiplying the single friction along the sides—as given by the empirical formulæ for the case of uniform motion—by the space traversed in consequence of this mean velocity.

Mr. Boussinesq has shown since 1870-71 that this hypothesis as to the work of the frictions is inexact in two ways. Also he does not employ the theorem of *vis viva*, the use of which it seems should in this case be given up; for there is nothing to show *à priori* in non-uniform motion what the work of the internal forces should be.

He makes use of the theorem of 'quantity of motion', or—which amounts to the same thing—he states in the manner of Euler the three equations of dynamic equilibrium—in one longitudinal sensibly horizontal direction, and in two directions at right angles, whereof one is sensibly vertical,—of a rectangular fluid element, under the action of its weight, of its inertia, of the normal pressures on it, and lastly of the friction or tangential forces applied to its faces.

He confines himself to considering *gradually* varied motion, styling thus that motion whose non-uniformity depends on quantities, the squares and products of which are supposed negligible in the investigation: such is, among these quantities, the inclination of the fluid surface to the bed over which it flows.

5. By considering at first only those parts of the current in which the curvature of the stream-lines is insensible, so that the centrifugal forces may be omitted, there results for the pressure from two of the differential equations its simple hydrostatic value. Substituting into the first of the three, and integrating all the terms from the surface to the bed or sides, there remains no other friction but that which they exert against the stream-lines flowing along their surfaces. The inertia which depends on the longitudinal acceleration is expressed by the sum of three differential terms which the author reduces to a single one by means of the equation of *continuity* or of conservation of volumes, by coupling it with the assumption—here sufficiently approximate—that the small inclination of the stream-lines is uniformly-varying from the surface or from its central line to the bed or borders.

He arrives thus at an equation of motion which has some analogy with that furnished by the theorem of *vis viva*; but there are two essential points of difference.

One consists in this that the term arising from the inertia is equal to the differential coefficient of the height due to the mean velocity with respect to the longitudinal abscissæ, multiplied—not by Coriolis' coefficient α, but—by another quantity, the excess of which above unity is only about a third as great, and which is the mean ratio of the *squares* of the individual velocities to the mean velocity through a similar section instead of being that of the *cubes* of the same velocities.

The other difference arises from the frictional retardation at the bed or at the sides. This friction depends on the velocities of the stream-lines adjacent thereto: now the ratios of these to the mean velocity are different in variable motion to the ratios in uniform motion. In order then to obtain the true value of the friction in question, or of the surface-slope necessary for its being overcome, it becomes necessary to add to the term expressing the value assigned to it in uniform motion for a like mean velocity another term depending on the degree of convergence or divergence of the stream-lines. As the quantity by which this degree is measured is supposed very small, so that, as has just been said, its square may be neglected, it appears that this term, *i. e.*, the additional slope in question, becomes the differential of the height due to the mean velocity multiplied by a numerical coefficient which varies slightly with the shape of the fluid section of the water-course under consideration.

Calling this second coefficient ϵ, and the first $1 + \eta$, (*viz.*, that which in the expression of inertia arises from the inequality of the velocities through each section), the surface-slope I, which may also be denoted by $\frac{d\zeta}{ds}$ *viz.*, the differential coefficient of the ordinate ζ of the fluid surface above a fixed horizontal plane with respect to the longitudinal abscissa s, lastly the density ρ, gravity g, and the mean intensity of friction F_u per square unit of the bed and sides round the section whose abscissa is s, *viz.*, the same as that intensity would be in a uniform motion with same mean velocity U, same cross-sectional area ω, and same wetted border χ, the new equation now under consideration is

$$\frac{d\zeta}{ds} = I = \frac{\chi}{\omega}\frac{F_0}{\rho g} + (1 + \eta + \epsilon)\frac{d}{ds}\left(\frac{U^2}{2g}\right)$$

6. To calculate these two coefficients $1 + \eta$ and β which are to multiply the s-differential coefficient of the height due to the mean velocity U of the fluid, the individual velocities of which it is the mean must be known for each section. The determination of any one of these velocities depends on a differential equation of the second order, whose second member contains the square of the unknown quantity involved in an integral multiplied by the small quantity which is the measure of the degree of variability of the motion.

7. It cannot be exactly integrated, but the author solves it by an ingenious process of successive approximations. It consists in replacing this second member at first by zero, *i. e.*, by provisionally suppressing the terms due to the non-uniformity: and obtaining then by an easy double integration of its terms throughout the whole fluid section a first approximation giving in uniform motion the particular velocity sought: and substituting then this expression, which is a binomial of second degree in the second member restored.

The integrations of the terms, after this substitution, are as easy as when this member is wanting, and there results thence for the velocity at any depth an expression of the sixth or ninth degree according as the section is rectangular and wide, or circular; and this expression leads to the second approximation to what is sought. Now this is sufficient in the problem in hand; for if an expression for the third approximation be formed (which would be just as easy) by the same process, it would differ from that given by the second only by terms affected by those squares and products of very small quantities which have been neglected throughout the whole course of the investigation.

The numerical coefficient $1 + \eta$ and ϵ may easily be found from this. It is seen that they are functions of the sole ratio $B \div A$ of the two quantities A, B which enter (Art. 3) respectively into the expressions assigned to the internal or mutual friction between stream-lines, and to the external or border friction.

For rectangular sections of much greater breadth than width, there results

$$1+\eta = 1 + \tfrac{1}{45}\left(\frac{B \div A}{1 + \frac{1}{3} B \div A}\right)^2, \quad \mathfrak{E} = \tfrac{4}{45}\,\frac{B^2}{A^2}\,\frac{1 + \frac{2}{7} B \div A}{(1 + \frac{1}{3} B \div A)^3}$$

and for circular or semicircular sections,

$$1+\eta = 1 + \tfrac{1}{25}\left(\frac{B \div A}{1 + \frac{2}{5} B \div A}\right)^2, \quad \mathfrak{E} = \tfrac{4}{25}\,\frac{B^2}{A^2}\,\frac{1 + \frac{4}{11} B \div A}{(1 + \frac{2}{5} B \div A)^3}$$

or respectively, adopting $B \div A = 1{\cdot}2674$, given as has been said by the mean of results of experiments on uniform motion,

$$1 + \eta = 1{\cdot}0176, \ \mathfrak{E} = {\cdot}0675,$$
$$\text{and } 1 + \eta = 1{\cdot}0283, \ \mathfrak{E} = {\cdot}1097.$$

Hence there results

$$1 + \eta + \mathfrak{E} = \begin{cases} 1{\cdot}0851 \text{ in wide rectangular channels,} \\ 1{\cdot}1380 \text{ in semicircular channels.} \end{cases}$$

The arithmetic mean of these two numbers is 1·11. It is nearly the value which many Engineers adopt in practice for the coefficient a of Coriolis multiplying like $1 + \eta + \mathfrak{E}$ the differential of $U^2 \div 2g$ in the Equation of motion. This apparent agreement ought not to give rise to the idea that the new mode of establishing what relates to permanent motion amounts in the least degree to the other, which we have explained to be vitiated by two errors.

Coriolis, who with assumed data as to the distribution of the velocities of the stream-lines, raised the value of a up to 1·18 and even to 1·47 would have obtained only 1·0515 had he determined as above what that distribution would be in a rectangular bed presenting like most natural water-courses a width much greater than its depth: so that the agreement of the results has in fact no more real existence than the agreement in principles.

Mr. Boussinesq remarks also that pretty approximately

$$\mathfrak{E} = 3{\cdot}85\,\eta$$

for both of the extreme figures of section, and that this ratio 3·85 of $\mathfrak{E}$ to η obtains very closely even when the numerical value of $B \div A$ is very sensibly varied. This peculiarity gives the means of approximately deducing $\mathfrak{E}$ from η, which is easier to calculate for sections of all figures, because it depends to the degree of approximation proposed only on the distribution of velocities in the case of uniform motion.

Further, as the differential of the height due to the mean-velocity is small in the motion which we have styled *gradually varied*, small errors in the values of the coefficients η and $\mathfrak{E}$ have little effect, and it is permitted, without fear of sensibly altering the results, to introduce into the calculations of the ratio B $\div$ A on which they depend, the use of a formula, which like that of Tadini $\frac{\omega}{\chi}$ I $= \cdot 0004$ U^2 represents only a mean of the results of a great number of observations on water-courses of all sizes with earthen sides.

This use is no way prevents the use of more exact empirical formulæ, such as those of M. Bazin, to assign the value of the principal term of the equation of motion, *viz.*, the portion $\frac{\chi}{\omega} \frac{F_u}{\rho g}$ of the surface-slope, which would be due to the total friction against the border for the like mean-velocity in uniform motion.

It is seen also, and this is not one of the least useful consequences of the analytical investigation which Mr. Boussinesq has undertaken, that there is no need of taking the trouble, as has sometimes been done, of effecting the integration by curvilinear co-ordinates or by other difficult methods of an equation in the velocities for sections of various shapes.

It may be concluded that there would be thence deduced for the quantity by which to multiply $\frac{d}{ds}\left(\frac{U^2}{2g}\right)$ numbers not deviating sensibly from those which have just* been given.

7. The author deduces (§§ xiii, xiv) from the equation so established, various general consequences.

A constant supply from above, and a constant mode of drawing off or discharging from below, determine a permanent state, or even more generally over long lengths a motion so gradually varied as to be defined by the equation just given: so that it suffices to be given for any point, together with the discharge, either the depth of water if an open channel is in question, or the pressure if a pipe is in question, to deduce numerically all the rest by successive approximation. But these portions may, even

* M. Boussinesq has shown further on (Art. 45 of his Memoir) that the following obtains *for every figure of section*;

$$\varepsilon = 2\alpha - 2(1 + \eta),$$

that is to say, $$\varepsilon = 2\int^{\cdot}\left(\frac{u}{U}\right)^3 \frac{d\sigma}{\sigma} - 2\int^{\cdot}\left(\frac{u}{U}\right)^2 \frac{d\sigma}{\sigma},$$

u denoting the velocity across any element whatever $d\sigma$ of the cross-section σ, through the whole extent of which the two integrals are taken: and the mean U being $\int^{\cdot} u \frac{d\sigma}{\sigma}$. This agrees sensibly with $\beta = 3{\cdot}85\,\eta$ inasmuch as $\alpha = 1 + 2{\cdot}925\,\eta$ more approximately than $1 + 3\,\eta$. It is seen that the complete coefficient $1 + \eta + \varepsilon$ which enters into the new Equation of permanent motion exceeds one almost $\frac{2}{3}$ times more than Coriolis' coefficient α for the same distribution of the individual velocities across each section.

with a bed and borders of straight longitudinal section, be separated by shorter portions, in which the flow follows other laws little known or even unknown, for which however an approximate allowance may be made by use of two principles, *viz.*, for pipes that of the loss of *vis viva* of Borda, and for canals that of the formula of "afflux" (ressaut) of Bélanger: for they give a relation either between the pressures or between the depths of water above and below these portions. The author introduces an improvement into these two principles by taking account immediately below as well as above of the inequalities of velocity of the different stream-lines, and especially of that part of the friction against the border which arises, as has been said, from the fact of the motion being variable.

He arrives thus at results agreeing very satisfactorily with experiment, for he obtains for instance the true coefficient ·82 of the discharge given by cylindric adjutages, whilst Borda's principle as commonly applied gives ·85.

Next (§ xv, xvi), he considers the particular case of a channel whose bed is prismatic, or is at least such that the water *can* flow in it with a nearly uniform motion. Uniformity tends to become established therein; but without altogether exceptional arrangements at the head and exit, there are always two reaches in the upper and lower portions of more or less great extent, in which a uniform state cannot take place. There is then in general a portion of the current in which uniform motion *becomes established*, and another in which it *becomes destroyed*. This destruction at the lower end, takes place with or without "afflux" (ressaut), according as the velocity of uniform motion is greater or less than that which would be required by a body falling freely from a height equal to the mean half-depth corresponding to the same condition, this height being divided by the coefficient somewhat greater than one, above styled $1 + \eta + \epsilon$.

If it be admitted, as the author remarks, that the mean friction per square unit of the bed has for its measure in uniform motion, the product of the square of the mean-velocity by a constant quantity, the distinguishing character of the two cases becomes the value of the slope in one case less than, and in the other greater than, the quotient of that number by the density of the water and by the same coefficient $1 + \eta + \epsilon$. This makes with the mean data above

$$\frac{\cdot 00049}{1 + \eta + \epsilon} = \frac{\cdot 0004 \times 9\cdot 809}{1\cdot 085} = \cdot 00361,$$

for the slope which separates the two species of water-course, to which it was proposed by one of us in 1851 and in 1870 to assign the two names *River* and *Torrent*, as their relative properties are well in accord with the ideas commonly attached to these two expressions.

8. After a digression (§ xvii) upon the effects produced in the end by the action of the waters on the surface of the earth, to which they give the form of a surface marked with undulations, as well as on the real character of ridge and valley lines which separate them, and after having (§§ xviii, xix, xx) established the equation of motion, including the effect of curvature and centrifugal forces, Mr. Boussinesq returns (§ xxi), having introduced this last element, to the circumstances which precede the establishment and the destruction of uniform motion; and he proves the necessity of distinguishing an intermediate class of water-course, which he has termed *Torrents of moderate slope.* He finds that it is necessary to lower the upper limit of slope for Rivers about ·0003, (or to reduce it to ·0033 on the average), if it be proposed that the down-stream conditions of destruction of uniform motion, should be calculable without taking into account the curvature of the fluid surface.

In similar water-courses of the first class (*viz.*, Rivers), uniform motion becomes established up-stream, or where the state changes in the passage downwards from a variable to a uniform motion with a surface swell, and therefore with sensible curvatures, which must be taken into account.

In Torrents of steep slope, the mean lower limit of which must then be raised to ·0039, uniform motion becomes on the contrary gradually established without sensible curvature intervening; and it is destroyed down-stream rapidly, or as above explained, with an "afflux" (ressaut).

Lastly, in the intermediate kind of water-course, the bed-slope of which would be included between the limits of ·0038 and ·0039, the effect of the curvature of the stream-lines is not negligible either at the spot where the state is established, or at that where it is destroyed to give way to variable motion down-stream; so that these *Torrents of moderate slope* partake of the two other kinds of water-course under the relations in question.

9. The author arrives (§§ xviii, xix) at the complete equation just mentioned by taking count of the curvatures, and preserving in the investigation the dynamic portion of the pressures due to the transverse components of the accelerations or to the deviating forces of inertia.

They are expressed by three differential terms, which he succeeds in reducing to a single one by means of the equation of continuity, when the channel is supposed to be of constant width.

The calculation of these forces, and its result in particular, would be of excessive complexity, if carried out with strict regard to the difference of velocity of different stream-lines. So the author confines himself to indicating the steps; and as the terms due to the centrifugal forces are, after all, very small compared with the rest under the conditions supposed to be fulfilled, he replaces in the reduction of the new terms all these velocities by their mean U.

He finds by two approximations obtained as above that, if i denote the bed-slope of the channel, h the depth of the water, and therefore $\frac{di}{ds}$ the curvature of the bed, $\frac{dI}{ds} = \frac{di}{ds} - \frac{d^2h}{ds^2}$ that of the surface, it is sufficient, in consequence of the equation of conservation of volume $h\text{U} =$ const., to subtract from the term $(1 + \eta + \mathfrak{C}) \frac{d}{ds}\left(\frac{\text{U}^2}{2g}\right)$ of the equation (Art. 5) of motion in straight lines the expression

$$\frac{\text{U}^2 h}{g}\left(\frac{1}{3}\frac{d^2\text{I}}{ds^2} + \frac{1}{6}\frac{d^2 i}{ds^2}\right) = h^2\left[\frac{1}{3}\frac{d^3}{ds^3}\left(\frac{\text{U}^2}{2g}\right) + \frac{1}{2}\frac{\text{U}^2}{gh}\frac{d^2 i}{ds^2}\right],$$

to obtain the equation of motion in curved lines.

This equation, like that proper to rectilinear motion, enables the numerical determination by successive approximation of the succession of surface-slopes which a given discharge will cause in a current, by averaging a few more initial data.

10. But it yields also several general results. In fact if it be assumed first (§ xx) that *the bed has no curvature*, or that there is none except at the water surface, it reduces to a differential equation of third order in h and s which becomes linear and integrable when, instead of the variable depth h of the water, the ratio $\varpi = \frac{h - \text{H}}{\text{H}}$ by which that depth exceeds the depth H corresponding to a uniform motion with same discharge is taken for the unknown quantity, and when that ratio is supposed not very great. The integration gives Mr. Boussinesq, in the discussion of its results, a large number of curious properties relating to the places where uniform motion begins or ends. The integral is the sum of three exponentials multiplied by arbitrary constants, sometimes finite, sometimes zero, with exponents, whereof one is always real, and the other two sometimes real, sometimes imaginary. The periodic form which results from the occurrence of imaginaries shows that in those parts of Rivers or *moderate Torrents* where uniform motion begins, the fluid surface is affected by a train of transverse waves all of the same size lengthways of the current, with heights ϖ H rapidly decreasing, and soon effaced in proceeding down-stream or towards a longitudinal rectilinear asymptote about which the wavy surface vibrates. The exponentials have real exponents, and there is no undulation at the spot where uniform motion begins in the case of the torrents classed above as rapid, and also at all the places where this state is destroyed quietly in the case of Rivers, and with "afflux" (ressaut) in the case of Torrents.

But the "afflux" (ressaut) in the case of moderate or not very rapid Torrents does not take place quite abruptly. In fact in the differential equation relating to them, and in which the proportionate elevation ϖ is involved in the third order, it is necessary, in order to obtain its value beyond a certain magnitude, to preserve the most important of the terms which prevent the equation from being linear. It is then to be solved by a process of successive approximation: this process gives an expression which by its form facilitates the study one by one of the various parts of the longitudinal section of the "afflux" (ressaut).

These portions which merge into one another are alternately concave and convex. The author succeeds by other artifices of approximation in calculating the ordinates of the summits and hollows of these waves which rise by steps to the level of the top of the "afflux" (ressaut).

The experiments of Mr. Bazin lend a remarkable confirmation to this theory. The numerous cases of "afflux" (ressaut) which this engineer has experimented on are some *long* and some *short*. The former are produced in moderately swift Torrents, and are always furrowed by transverse waves as if the upheaval of the water was as it were hesitating and ill assured. The latter, produced solely in water-courses of high slope, are the only cases in which the water surface rises without oscillation all at once, and as if vigorously pushed by the following water, although there is sometimes even in this case, but after the swell and not below it—a certain number of transverse waves.

11. Reintroducing the curvature of the bed, two interesting articles are devoted to studying the effect which it may have, especially when it is alternating or in two opposite directions, on the fluid surface, the mean depths being a little above or below those of uniform motion with same discharge and same *general* or *mean* slope of bed. The integration is especially easy when the curvature of the bed presents undulations all of same length supposed sensibly greater than the depth of water. And if they be also of same height, the result shows that the surface will itself present regular undulations generally *in advance* of those of the bed, but synchronous in one remarkable case.

Of all water-courses, Torrents *of moderate slope* are those whose surface repeats to the fullest extent regular undulations in the bed. Rapid Torrents come next, and those which have the highest slope diminish their vertical height, &c.

12. The third and last part of Mr. Boussinesq's memoirs (§ xxvi, at the end) treats of *non-permanent* motion supposed always slowly varying. Dupuit was the first to seek the equations thereof; one of the two which he has laid down, that which expresses continuity or conservation of volume of the fluid sections is exact, but applicable only to a rectangular canal, with velocities supposed all equal through any one section. He was mistaken in the other, and one of us has established in different terms this principal equation into which the slope, the inertia, and the friction over the bed enter.

Mr. Boussinesq, after having verified it for the case proposed in the same way as the extension, which had been given to the former for all figures of section and all distributions of velocity, has succeeded in establishing the principal equation, taking account also of the inequality of velocity of the different stream-lines, and even afterwards of their curvature, by making use of the same formula for internal and external friction, as well as of the same method of successive approximation which he had used in the case of steady motion.

This equation, together with that of continuity, expressed with the above notation, except for a numerical coefficient, *viz.*,

$$\epsilon'' = \frac{2}{945}\left(\frac{B \div A}{1 + \frac{1}{8} B \div A}\right)^3 = \cdot 00149 \text{ on the* average,}$$

are for the case of a rectangular channel, noting that $\chi \div \omega = h$, and neglecting the curvature in the first instance,

$$\text{I, or } \frac{d\zeta}{ds} = \frac{1}{h} \cdot \frac{F_u}{\rho g} + (1 + \eta + \epsilon) \frac{d}{ds}\left(\frac{U^2}{2g}\right) + \frac{1 + 2\eta}{g} \frac{dU}{dt} - \frac{\eta - \epsilon'}{g} \frac{U}{h} \frac{dh}{dt};$$

* The author finds that this coefficient is sensibly the same as $2\eta - \frac{1}{2}\epsilon = 3\eta - (a - 1)$.

He transforms the former of these two equations by help of the second and introducing the slope of the bed

$$i = 1 + \frac{dh}{ds}$$

at the same time that he assigns to the friction over the bed F_u of the case of uniform motion a value $\rho g b U^2$, where b is a coefficient supposed as above only slightly variable, he draws thence further on various consequences.

When the bed and surface have curvature of sensible magnitude, denoted by $\frac{di}{ds}$, $\frac{dI}{ds} = \frac{di}{ds} - \frac{d^2h}{ds^2}$, it is necessary in calculating their small effect in the same way as above, as if all the velocities were equal to the mean U, to add to the second member of the former equation the term

$$\frac{U^2 h}{g}\left[\tfrac{1}{3}\left(\frac{d^3h}{ds^3} + \frac{2}{U}\,\frac{d^3h}{ds^2dt} + \frac{1}{U^2}\,\frac{d^3h}{ds\,dt^2}\right) - \tfrac{1}{2}\,\frac{d^2i}{ds^2}\right]$$

But the author remarks further on (§xxxvi) that there are circumstances, for instance in the investigation of the propagation of waves in a direction contrary to the motion of the water in a channel, in which the inequality of the velocities may affect the magnitude of the centrifugal forces; and he gives the results of long investigations from which there arise terms involving the second differentials of h, besides those which involve the third differentials.

13. Without entering into the numerous carefully worked out details which this delicate and difficult part of his memoir contains, we may mention succinctly the application which he makes of the equations of non-permanent motion to the investigation of the propagation of waves and swells in sloping channels, in which the water is animated with a permanent motion approximating to a uniform state.

He finds for the small elevation h' of the water above its primitive surface

$$h' = F_1(s - \omega_0' t) + F_2(s - \omega_0'' t),$$

F_1, F_2 being two arbitrary functions, and the two ω_0 being given by a formula with a double sign approximating to

$$\omega_0 = (1 + 1{\cdot}9\,\eta)\,U_0 \pm \sqrt{(1 - 2\,\eta)\,g H + \eta\,U_0^2},$$

wherein U_0 is the primitive mean velocity of the water, H is its depth, and lastly η is the small number whose average value is ·0174 defined above (Art. 5), and whose presence in this formula measures the influence of the inequality of velocity of the stream-lines across each section.

This expression for ω_0 gives in absolute terms the velocity with which a wave is propagated in the channel according as it advances up or down stream. It would reduce, without the inequalities in velocity of the stream-lines to the expression $U_0 \pm \sqrt{gH}$ of Lagrange and of J. Scott Russell, which suffices in many cases, but not when treating of waves passing up a current of small velocity; and Mr. Bazin has noticed in fact that the expression $\sqrt{gH} - U_0$ gives then too high values.

Mr. Boussinesq finds also that waves of small height may pass up the channel of a *River* but not up that a *Torrent*: and this too agrees with Mr. Bazin's experiments.

14. After some considerations on the reflexion of waves, producing composite effects, which are represented by the sum of the two arbitrary functions F_1, F_2 above, Mr. Boussinesq passes on (§ xxix) to the closer approximation resulting from taking curvature into account.

To this end, in the equation wherein are involved the small height h' of the wave or swell and the small increase of horizontal velocity which results from its formation, he renders linear the terms which are not so by substituting therein for these two unknowns the values which had been found in the first approximation. The equation is then easily integrated by introducing therein as a new unknown (as had been done in a former memoir), the velocity or *celerity* of propagation *proper to each point*, an apparent velocity, which he defines most neatly as the space through which a transverse vertical plane *having always the same volume of the heaving water in front of it* advances in a time-unit. He finds thus for this celerity ω, one of those just denoted by ω_0 multiplied by a trinomial, whose first term is 1, whose second is multiplied by the height of the swell at the same particular point, and the third by its second differential coefficient with respect to the longitudinal abscissa, with numerical coefficients which in the memoir quoted were of simple form, approximate only because the differences of velocity of the stream-lines were not there taken into account.

15. Considering in particular (§ xxx) the case of waves which are propagated in a liquid in repose, the author determines all the circumstances of them, such as the height of their centre of gravity, the celerity of propagation proper to this centre, the *energy* of the wave, or the work which it would produce during its effacement if the fluid returned to rest, its *moment of instability*, denoting thus (§ xxxii) the tendency to deformation in its advance, and even to separation into several other waves, and lastly the curved figure of its surface.

This form is stable, and the moment just named is at a minimum for the particular wave styled *solitary* by Mr. Russell.

It is the only one which is not deformed in its propagation, or which enjoys that *longevity* which the same experimenter attributes to it.

Mr. Boussinesq finds also (Art. 161), and which is also confirmed by experiment, that when a wave is propagated in a channel whose depth decreases in the direction of its propagation, as it results from the superposition of a direct and of a reflected and increasing portion, it becomes in its advance less bulky and more elevated, and consequently shorter and less and less stable until it gives way at the base and produces that state of "breaking" which is observed on shores of gentle slope, a well known phenomenon, which has not hitherto been so completely explained.

The contrary would take place if the depth of water continued to increase.

16. When a swell is supposed continuous (§ xxxiii), like that produced by the influx also continuous of a constant quantity of water at any point of a channel with water originally still, the same analysis proves that its velocity of propagation, or the length by which it increases per time-unit is about $\sqrt{g\,(H + \frac{3}{2}\,h')}$, if H is the primitive depth of water, and h' the nearly constant height of the swell. But if it be considered what ought to take place at its crest or in that part of the swell which advances in front, it is seen that the height cannot there be the same as in the rest, for it has necessarily a curvature, which according to the formula with the trinomial parenthesis just mentioned, would render the velocity there smaller than in the successive portion. This latter part would spread over the former and would swell it up until its velocity increased by this alone became the same. Thus is explained the prominent *initial wave* which has been constantly observed by Mr. Bazin.

But this is not all. This crest or initial wave cannot merge into the rest but by a surface having a concave portion, which determines by a development of centrifugal force an increase of velocity which tends to break it up: whence a train of alternately concave and convex portions or of waves of less and less height in receding; as experiment also shows.

The same law of the velocities of propagation of the different parts of a wave according to their height and curvature gives also account of the more rapid change of form of negative waves, *viz.*, such as have hollows instead of swellings.

17. When continuous waves, formed in succession and superposed have a barely sensible curvature, the curve forming the envelope of their crests at any given instant can be found by an easy integration. It is a solution of the problems of tides and floods in rivers, but giving certain results only when the total height of the swell is but a small fraction of the primitive depth of the water. When it is greater another kind of solution becomes necessary.

In three later articles (§§ xxxv, xxxvi, xxxvii), the author determines the modifications which the conclusions undergo when the original slopes, curvature, friction at work, and inequality of velocities are all taken into account at once. He finds (§ xxxvi) that waves decrease in height gradually in their propagation along a current especially when proceeding up-stream, and the more so as the velocity of the current is higher. This also has been observed by Mr. Bazin.

As to the effect of friction and of bed slope not on the height, but on the celerity of propagation, it is to decrease or increase it with respect to an observer animated with the velocity of the current, according as waves proceeding down-stream or up-stream are in question. The leading portion of a sufficiently long continuous wave advances thus generally quicker than the body of the wave; whence it follows that the wave becomes thinner in such a way as to turn its concavity or convexity upwards according as it is positive or negative. This is the effect which Mr. Bazin has noticed in very long waves proceeding up-stream, and it is perceptible even in ripples (remous) propagated along a horizontal channel.

18. These numerous results of a high analysis, based on a circumstantial discussion, as well as on judicious comparisons of quantities of various orders of minuteness, sometimes preserving them, sometimes neglecting or rejecting them, and their constant agreement with the results obtained by the most careful experimenters and observers have seemed to us the more remarkable.

That which serves as the basis, to wit, the formulæ which have been mentioned in the first part of this report, formulæ based on a distinction of two sorts of motion in liquids and established by the author, after having proposed, for the calculation of the mutual friction between their layers or stream-lines, expressions which take into consideration their state of various intensities of agitation, and which give moreover results which are verified by actual fact, seems to us to give the solution in a new and happy manner with the desirable approximation, as far as it is possible to judge thereof in the present state of knowledge, of important questions having a practical bearing, and which have often been the aim of long and barren attempts.

The author's work is, as has been seen, conceived and executed in a spirit consistently positive and concrete, even though calling to his aid the resources of an advanced theory.

We consider it then as well worthy of your approval, and we propose its insertion in the " Receuil des Savants Etrangers."

Translator's Note. The Report above given abounds in references to Works on Hydromechanics and Hydraulics, chiefly French, and mostly accessible only with difficulty to English readers (especially in India). It has not been thought worth while to reproduce these.

A. C.

No. CCXCI.

SCANTLINGS OF DEODAR TIMBER FOR FLAT ROOFS.

[*Vide* Plate.]

Communicated by the Secy. to Government Punjab, P. W. Department.
Extracts of Circular No. 44, dated Lahore, 30th November, 1877.

THE calculation of the scantlings of deodar timber for flat roofs has been subject to uncertainties and inaccuracies from various causes.

It had appeared that the coefficient of strength in ordinary use deduced from experiments on deodar made at Attock in 1856, and at Roorkee in 1858, was too large. And the results of the experiments recently made show that this was the case.

One of the chief causes of the erroneous results obtained from the old experiments referred to,—a probable cause of error in most experiments of the kind, not in India only,—is the small size of the specimens with which the experiments were made. It was with reference to this defect that a set of five experiments were made at Chatham a short time ago on pieces of Memel Fir of large dimensions, the results of which were published in the *Royal Engineer Journal*, March 1st 1876. The nature of the error is, generally, that the strength, deduced from experiments on small pieces, is too great.

Again, scantlings calculated from the *Strength* formula, dependent on the coefficient obtained from breaking weights, even if correct, are not always sufficient to secure the required *stiffness*. And it was necessary to calculate the scantlings likewise by the *Deflection* formula, and adopt the larger result. The mode in which the use of the strength formula only has been made to answer the same purpose, according to very usual practice, was to apply such a factor of safety as ensured its covering the result given by the other method. But this was not an accurate procedure though, considering the very various results of even the best experiments, its inaccuracy may not have been greater than that of the experimental data it assumed.

The very various results of experiments, above adverted to, indicate a cause of possible defect or failure, in practice, of individual pieces, without implying any defect or error in the calculations. But this variety of results, noticed in all series of experiments on small pieces, is exhibited likewise in the Chatham experiments on pieces of dimensions adapted for use in actual construction (length 17 to 19 feet, scantlings 5 inches by 12 inches to 12 inches by 12 inches), which showed "that not only is the strength of timber of the same quality very variable, but also that the two halves of the same log are by no means of the same strength," (*see* page 47.)

A number of experiments, on pieces of good size, reduces the error that might be caused by this great variation, and gives mean values, which, *as mean values*, may be accepted. But then, in applying this mean value in practice, we have to remember that it may be no nearer the representation of the actual strength of any single piece we are using than is the average of the results of the experiments to either of the extremes. The piece we are using, may be one which, if tried, would bring out one of the maximum results, or one of the minimum. For this reason, as well as because no piece must, in an actual structure, be subjected to more than a small proportion of the force that would destroy it, must a large factor of safety be applied when using formulæ based on breaking weights.

The amount of the factor of safety is, in a measure, arbitrary. It is based, as fairly as possible, on experience. Different figures are accordingly assigned by different persons. And it is easy to see that, when the coefficients deduced from experiments have been so uncertain, there is room for much variety also in the experiences of actual practice, and in the factor of safety fixed by careful and accurate practical men.

It is seen that we are yet far from having very certain data for calculation of scantlings of timber by the Strength formula. But, while on this account avoiding over-refinement, and the error of treating as precise such experimental data as can be only approximate, it is very important to make the data, for both methods of calculation, and the mode of dealing with them, more accurate and trustworthy, by numerous careful and well-conducted trials and observations, both on strength and on stiffness. This was the object of the experiments recorded in the accompanying papers.

Among the varieties that have been noticed of the strengths of the same kind of timber, it has been observed that wood obtained from different places showed different strength. The mean of the coefficients deduced from the breaking weights of deodar from Garhwal, tried at Roorkee, was $\frac{1}{28}$th higher than that of a certain Punjab deodar tried at the same time. It had been suspected, after some experience of it, that the particular wood in question, in use in the Punjab, was not so strong as other wood of the same kind which had been used elsewhere, and it was to test this that these experiments were made.

The conditions which it has been thought might possibly affect the structure and strength of wood from different places are,—the elevation at which the trees grew, and the moisture or dryness of the locality affecting the rapidity of growth and compactness of the annual rings. Also the time at which the timber was felled, the time that has passed since, and the kind of seasoning it has had, or treatment to which it has been exposed.

Opportunity has been taken to consult the Inspector-General of Forests on these and other points. Dr. Brandis is of opinion, that nothing at present known regarding the structure of trees grown under different conditions gives reason to believe that the strength is affected by the elevation at which they were grown, or the moisture of the climate. But that the working quality of the timber may certainly be affected by the time it has been felled, and the manner in which it has been treated. Dr. Brandis has also observed that the circumstance of pines having grown close together or far apart has an effect on their strength; on this wise, that the former being more straight, with fewer branches and fewer knots, are on this account stronger than the others whose growth is more free and varied.

With reference to these enquiries regarding conditions possibly affecting the strength, Dr. Brandis has directed attention to the remarks on the subject in a short treatise* by MM. Chevandier and Wertheim on the mechanical properties of timber. The results of the experience of various authorities are quoted with respect to the circumstances affecting the structure and strength of trees and different parts of them,—the influence of soil,—the effect of rate of growth,—the differing strength of pieces of equal scantling cut from the branches and from the trunk,—and of pieces from the upper and lower parts of the trunk,—and from

* Mémoire sur les propriétés mécaniques du Bois; par MM. E. Chevandier et G. Wertheim.

different parts of the trunk from the middle to the outside (*see* above page 46),—the effect, on different sides of the tree, of exposure to different points of the compass,—the difference of the timber of trees of different age,—of wood recently felled and the same when dry,—the relation between weight and strength,—and, in connection with this, the different densities of the trunk near the root and further from it.

With regard to some of the most important of these circumstances, as the authors of the treatise referred to observe, the diversity of the results and opinions quoted leaves the questions in much uncertainty. The influence of some of them appears to be confirmed by the investigations of MM. Chevandier and Wertheim. With others of these circumstances they found the quality of the wood not to have any determinable connection.

Nevertheless the influence of these various circumstances, or of some of them, (though the nature and degree of that influence is uncertain,) may possibly so affect particular specimens of timber, or a whole collection, as to vitiate the conclusions drawn from a set of experiments, or disturb the expected relation between strength and dimensions of pieces used in actual construction. It is manifest that with so many possible causes of difference in the strength of different pieces of the same wood, a great number and variety of experiments would be necessary to furnish data of the precise kind that is desirable for practical application. And every careful and accurate contribution to this knowledge is of much practical value.

The experiments on transverse strength have been made with pieces of larger dimensions than ordinarily used in previous similar experiments, and are thus of higher value.

The experiments are not in sufficient number to furnish any very definite conclusions, but they appear to show that in resistance to *crushing*, which is more directly exhibited in the experiments on the shorter pieces, the *Jhelum* timber is stronger than that from the *Chenab* in the proportion of 1 to ·867. And stronger in the proportion of about 1 to ·946 in resistance to *pressure* with *flexure*, as shown in the experiments on the longer pieces.

It will be seen that the crushing stress per square inch is less in these Punjab Deodars than that assigned in the ordinary published tables to the several descriptions of European and American pines. But without knowing how far the methods of trial from which the figures are deduced were similar, no proper comparisons can be made.

As a contribution to our knowledge of the strength of timber, the experiments shown in Table III. on resistance of Deodar timber, from the forest of the Chenab and Jhelum, to direct pressure conducted by Mr. D. Kirkaldy, a man of known skill and accuracy, with the most suitable means and appliances, will be of much value.

The experiments and the observations recorded in the accompanying statements, so far as they have gone, are believed to furnish very useful additions to our knowledge on the subject. The chief practical conclusions are these—

(1). In the application of the *strength* formula for calculation of scantlings of deodar timber under transverse strain, the coefficient should be taken as 300.

(2). The factor of safety to be applied should be 6.

(3). The formula and notation here understood are—

$$w = \frac{bd^2}{L} \times C \div f$$

$$\text{or } W = \frac{2bd^2}{L} \times C \div f.$$

Where w, represents the working or safe load in lbs. at the middle,

W, the distributed safe load $= 2w$,

b, d, breadth and depth, in inches,

L, length, in feet,

C, the constant for transverse strength, $= 300$ for deodar,

f, the factor safety, $= 6$.

Applying these figures the formula is—

$$W = 100\frac{bd^2}{L}$$

$$\text{and } d = \sqrt{\frac{LW}{100b}}$$

If a fixed ratio of breadth to depth is assumed, called $r = \frac{d}{b}$, then

$$d = \sqrt[3]{\frac{LWr}{100}}$$

A fixed ratio of breadth to depth is not necessary. The large proportionate depths, or small proportionate breadths, of flooring joists, according to common English usage, can usefully be applied in many instances, the thin timbers being properly supported by cross bracing to preserve their true position of strength.

TABLE

Report on Experiments conducted by Rai Kanhya Lal, Bahadur, Deodar Timber, obtained at Lahore,

Locality of produce,—Ravi, Ujh, Chenab or Sutlej	Number of specimen	Bearing in feet	Length in feet	Scantling in inches	Weight in lbs.	Loaded for 24 hours with approximately: $\frac{1}{20}$th breaking weight — Actual load	$\frac{1}{20}$th breaking weight — Deflection	$\frac{1}{10}$th breaking weight — Actual load	$\frac{1}{10}$th breaking weight — Deflection	$\frac{3}{20}$ths breaking weight — Actual load	$\frac{3}{20}$ths breaking weight — Deflection	Breaking weight
		ft	ft	Inches	lbs.	lbs.	Inches	lbs.	Inches	lbs.	Inches	lbs.
R	1	10	12	6 by 4	76·37	360·00	0·1	720·00	0·300	1,080·00	0·45	5,273·82
R	2	10	12	6 by 4	78·17	360·00	0·2	720·00	0·40	1,080·00	0·65	4,682·52
R	3	10	12	6 by 4	73·93	360·00	0·2	720·00	0·50	1,080·00	0·725	4,816·88
R	4	10	12	6 by 4	76·50	360·00	0·2	720·00	0·50	1,080·00	0·725	4,322·80
U	5	10	12	6 by 4	62·74	360·00	0·3	729·00	0·50	1,080·00	0·70	4,222.00
U	6	10	12	6 by 4	68·92	360·00	0·2	720·00	0·40	1,080·00	0·575	5,148·00
U	7	10	12	6 by 4	75·22	360·00	0·4	720·00	0·70	1,080·00	0·9	3,091·47
U	8	10	12	6 by 4	74·57	252·00	0·1	720·00	0·2	1,080·00	0·3	5,051·78
C	9	10	12	6 by 4	67·63	252·00	0·025	504·00	0·125	756·00	0·275	4,892·87
C	10	10	12	6 by 4	65·00	252·00	0·025	504·00	0·2	756·00	0·35	5,699·65
C	11	10	12	6 by 4	66·00	252·00	0·1	504·00	0·2	756·00	0·30	5,598·21
C	12	10	12	6 by 4	67·11	252·00	0·1	504·00	0·2	756·00	0·35	3,784·85
S	13	10	12	6 by 4	67·83	252·00	0·2	504·00	0·4	756·90	0·60	2,984·88
S	14	10	12	6 by 4	69·42	252·00	0·1	504·00	0·3	756·00	0·50	2,162·03
S	15	10	12	6 by 4	66·34	252·00	0·125	504·00	0·25	756·00	0·40	3,606·14
S	16	10	12	6 by 4	65·57	252·00	0·15	504·00	0·30	756·00	0·40	3,511·51
R	17	6	8	5 by 3	25·33	312·68	0·1	625·37	0·175	938·04	0·25	4,424·23
R	18	6	8	5 by 3	30·47	312·68	0·1	625·37	0·20	938·04	0·30	4,954·57
R	19	6	8	5 by 3	28 28	312·68	0·05	625·37	0 125	938·04	0·20	4,237·68
R	20	6	8	5 by 3	27·77	312·68	0·1	625·37	0·20	938·04	0·275	4,745·40
R	21	6	8	5 by 3	25·72	312·68	0·025	625·37	0·10	938·04	0·20	4,374·22
R	22	6	8	5 by 3	34·97	312·68	0·05	625·37	0·10	938·04	0·20	3,865·60
R	23	6	8	5 by 3	27·77	312·68	0·10	625·37	0·2	938·04	0·275	5,248·88
R	24	6	8	5 by 3	28·16	312·68	0·10	625·37	0·175	938·04	0·20	4,894·41
U	25	6	8	5 by 3	32·27	160·96	0·012	321·92	0·050	482·88	0·075	6,140·13
U	26	6	8	5 by 3	31·88	160·96	0·012	321·92	0·050	482·88	0·10	6,005·84
U	27	6	8	5 by 3	31·88	160·96	0·025	321·92	0·050	482·88	0·10	5,776·40
U	28	6	8	5 by 3	27·25	160·96	0·075	321·92	0·150	482·88	0·225	4,147·03
U	29	6	8	5 by 3	33·30	160·96	0·013	321·92	0·100	482·88	0·20	1,876·09
U	30	6	8	5 by 3	32·91	160·96	0·100	321·92	0·125	482·88	0·20	6,122·51
U	31	6	8	5 by 3	33·94	160·96	0·100	321·92	0·200	482·88	0·25	3,168·0
U	32	6	8	5 by 3	31·88	160·96	0·025	321·92	0·050	482·88	0·10	5,476·0
C	33	6	8	5 by 3	26·74	160·96	0·025	321·92	0·100	482·88	0·125	5,259·4
C	34	6	8	5 by 3	25·46	160·96	0·050	321·92	0·100	482·88	0·15	3,956·3
C	35	6	8	5 by 3	27·77	160·96	0·050	321·92	0·100	482·88	0·2	5,179·2
C	36	6	8	5 by 3	27·77	160·96	0·050	321·92	0·100	482·88	0·175	5,008·4
C	37	6	8	5 by 3	31·88	160·96	0·100	321·92	1·250	482·88	0·20	5,139·8
C	38	6	8	5 by 3	29·30	160·96	0·025	321·92	0·100	482·88	0·15	5,162·4
C	39	6	8	5 by 3	29·34	160·96	0·013	321·92	0·075	482·88	0 10	3.080·8
C	40	6	8	5 by 3	30·34	160·96	0·050	321·92	0·100	482·88	0·15	2,557·6
S	41	6	8	5 by 3	26·87	160·96	0·075	321·92	0·100	482·88	0·20	4,302·3
S	42	6	8	5 by 3	26·35	160 96	0·125	321·92	0·175	482·88	0·20	3,185·5
S	48	6	8	5 by 3	27·38	160·96	0·025	321·92	0·050	482·88	0·10	3,746·4
S	44	6	8	5 by 3	25·72	160·96	0·025	321·92	0·075	482·88	0·10	4,289·2
S	45	6	8	5 by 3	27·77	160·96	0·050	321·92	0·100	482·88	0·125	4,1[illegible]9·
S	46	6	8	5 by 3	26·74	160·96	0·025	321·92	0·075	482·88	0·125	3,389·
S	47	6	8	5 by 3	27·77	160·96	0·075	321·92	0·175	482·88	0·25	3,712·
S	48	6	8	5 by 3	28·54	160·96	0·025	321·92	0·100	482·88	0·20	4,764·

of 48 Experiments,

I.

Executive Engineer, Lahore Division, on the Stiffness and Strength of under Central Loads.

Final deflection	Constant for transverse strain— $C = \frac{WL}{bd^2}$	Modulus of elasticity— $E = \frac{WL^3}{Dbd^3}$	REMARKS *Date of receipt of Specimens,* *16th April* 1876. „ *of commencement of Experiments* *10th May* 1876. „ *of conclusion* *of* „ *5th August* 1876.
Ins.	lbs.	lbs.	
2·30	366	2,778	Sharp close fracture; cracked with 38 maunds.
2·15	325	2,083	Has three knots. Half split in middle and broken with a long fracture.
2·80	334	1,667	Long splintery fracture.
2·30	300	1,667	Broke in three pieces with long splinters.
2·10	293	1,667	Broke in long splinters (had a flaw in the middle).
2·10	357	2,083	Sharp close fracture closely interwoven; had a knot on the lower part [in the middle.
2·0	215	1,190	Sharp close fracture; had a knot in the middle just below the load.
1·5	351	4,167	Splintery fracture.
2·4	337	4,667	Broken with long splinters.
2·3	396	2,917	Sharp close fracture.
2·4	388	2,917	Ditto.
1·6	263	2,917	Very long splintery fracture; the piece had a flaw in it.
1·8	207	1,458	Knot in the middle; fracture long splintery.
1·4	150	1,944	Flaw in ditto; ditto ditto.
1·7	250	2,333	Long splintery fracture.
1·8	244	1,946	Very long splintery fracture.
1·15	354	2,058	Sharp close fracture.
1·1	396	1,801	Ditto.
0·95	339	2,881	Sharp close fracture above and long splinters below.
1·0	379	1,801	Long splintery fracture below and sharp close fracture on upper part.
1·2	250	3,602	Sharp close fracture on upper part, long splintery below.
1·00	309	3,602	Ditto ditto ditto
1·05	420	1,801	Long splintery fracture.
1·4	392	2,058	Sharp close fracture; had flaw at the top.
1·3	491	3,708	Sharp close fracture.
1·4	480	3,708	Splintery fracture.
1·4	462	3,708	Sharp close fracture at top and splintery below.
1·3	332	1,236	Sharp close fracture.
0·7	150	1,854	Had a knot in the middle. Sharp close fracture.
1·4	490	1,483	Fracture long splintery.
1·1	253	927	Had two large knots; fracture splintery at one foot from the centre [at one of the knots.
1·2	438	3,708	Sharp close fracture above, and long splintery below.
1·7	421	1,854	Sharp close fracture.
0·9	316	1,854	Sharp close fracture on the upper side and long splintery below.
1·9	414	1,854	Sharp close fracture.
1·65	400	1,854	Sharp close fracture on the upper side and splintery below.
1·5	411	1,483	Sharp close fracture.
1·6	413	1,854	Ditto; twisted on side before fracture.
0·8	246	2,472	Ditto.
0·8	205	1,854	Ditto; a knot in the middle on the lower side.
1·10	344	1,854	Long splintery fracture.
0·90	255	1,060	Sharp close fracture.
0·80	300	3,708	Long splintery fracture; had a flaw in the middle.
0·95	348	2,472	Sharp close fracture.
0·90	329	1,854	Ditto.
0·80	271	2,472	Broke at a knot 15 inches from the centre; sharp close fracture.
0·13	296	1,060	Sharp close fracture.
0·13	381	1,854	Ditto.
...	336·58	2,286·41	

TABLE II.

Report on Experiments conducted by Ganga Ram, Assistant Engineer, Kangra Division, on the Stiffness and Strength of Deodar (received from the Chamba Hills by the Dehri River) under Central Loads.

Number of specimen.	Bearing in feet.	Length in feet.	Scantlings in inches.	Weight in lbs.	Loaded for 24 hours with approximately $\frac{1}{20}$th breaking weight. Actual load in lbs.	Deflection in inches.	Calculated value of E.	$\frac{1}{10}$th breaking weight. Actual load in lbs.	Deflection in inches.	Calculated value of E.	$\frac{3}{20}$ths breaking weight. Actual load in lbs.	Deflection in inches.	Calculated value of E.	Breaking weight.	Calculated value of C.	Final deflection.	Remarks and Observations.
			Inches.	lbs. oz												Inches.	
1	10	12	3 by 3	24 10	64	0·3	2,600	119	0·58	2,500	145	0·72	2,500	926	343	4½	Wood was dry and free from knots.
2	10	12	2·9 „ 2·9	24 0	50	0·3	2,300	100	0·6	2,300	150	0·97	2,200	808	330	4¾	Ditto ditto ditto.
3	10	12	3 „ 3	26 0	50	0·23	2,200	100	0·62	2,000	150	1·0	1,850	972	360	6¼	Ditto ditto ditto.
4	10	12	6 „ 4	58 16	258	0·18	1,600	537	0·39	1,600	787	0·58	1,700	2,580	180	2¾	Wood had three knots near the centre, but all of them were breadth wise. Coarse grained and crooked fibres; other two knots also crooked, but no fractures at those places.
5	10	12	2·8 „ 2·8	23 0	50	0·36	2,000	100	0·66	2,200	150	1·0	2,200	695	302	4½	Wood free from knots.
6	10	12	3·2¼	24 0	58	0·4	2,400	110	0·7	2,600	165	0·95	2,800	700	345	4½	Wood free from knots; broke into three pieces, middle piece being 1¼ feet long with inclined edges.

REMARKS AND OBSERVATIONS.

Strength formula, ... $C = \frac{WL}{bd^2}$

Stiffness ditto, ... $E = \frac{WL^3}{bd^3}$

W equal to central load in lbs.
L ditto length or bearing in feet.
d ditto depth in inches.
b ditto breadth in inches.
D ditto central deflection in inches.
E ditto modulus of deflectional elasticity.
C ditto coefficient of transverse strength.

Date of receipt of Specimens, not known. They were made out of Deodar which had been in Executive Engineer's store for about two years.

Ditto commencement of Experiments, 19th July 1876.

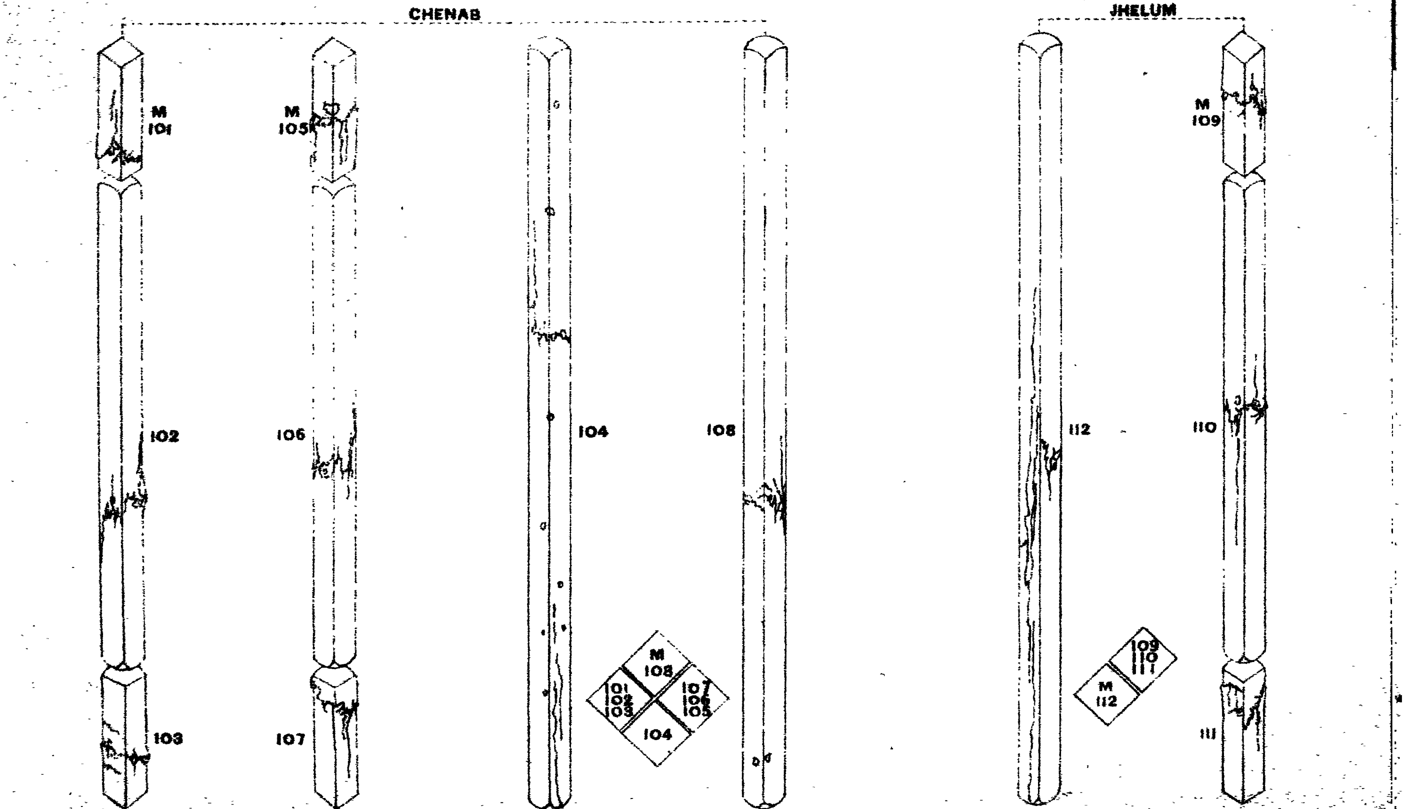
Ditto conclusion of Experiments, 18th August 1876.

NOTE.—*In these Experiments the ends were freely supported.*

An Experiment was conducted on piece No. 2 with ends loaded, and the result arrived at was as follows:—

No. of specimen.	Bearing in feet.	Length in feet.	Scantling.	Weights.	Central load	Deflection with free ends.	Deflection each end loaded with 25 lbs.	50 lbs.	75 lbs.	100 lbs.	140 lbs.	180 lbs.	220 lbs.	260 lbs.	Remarks.
			Inches.												
2	10	12	2·9 by 2·9	24	50	0·3	0·27	0·25	0·20	..	..	..	..	..	Further addition made no changes.
..	..	..	..	..	100	0·5	0·6	0 6	0·5	0·47	0·44	0·37		..	Ditto ditto ditto.
..	..	..	..	..	150	0 97	0·9	0·88	0 78	0·74	0·67	0·65	0·52	0·5	Ditto ditto ditto

SCANTLINGS OF DEODAR TIMBER FOR FLAT ROOFS.



For Dimensions and Results of Experiments—see Table III.

No. CCXCII.

ON A METHOD OF AVOIDING TRANSHIPMENT OF GOODS IN THROUGH TRAFFIC BETWEEN BROAD AND METRE GAUGE RAILWAYS, BY THE USE OF VEHICLES WITH MOVEABLE BODIES.

BY CAPT. W. SEDGWICK, R.E.

THE body of a covered goods wagon costs about one-fifth of the price of the entire wagon. The cost of the body in ballast, high-sided, low-sided and timber wagons is less than the cost of the body in covered goods wagons, and in the case of third class carriages, horse boxes, carriage, powder and luggage vans, the cost of the body is somewhat greater than in the case of covered goods wagons. Hence the present mode of construction, by which the bodies of all classes of vehicles are permanently fixed to the frames and wheels, does not seem a very economical one: for it obliges a railway to provide as many frames and wheels or expensive portions of vehicles as there are vehicles on the line; and it also obliges the frame and wheels of a vehicle to remain idle, while the body or inexpensive portion is being loaded, unloaded, repaired or kept in reserve for contingencies.

There seems no valid reason why there should not be one pattern of frame for all the commoner descriptions of vehicles, or why the bodies of these vehicles should not be mounted on small trucks or runners, so as to be readily run on to or off from the frames and wheels when necessary. Then, if lines of light rails were laid on platforms raised nearly to the level of the tops of the frames of the vehicles, the loaded bodies of the vehicles could, at the end of a journey, be run off the frames, and empty bodies, or bodies loaded for outwards traffic, run on, in their place, and taken away. Also a stock of bodies could be kept in reserve, so that, whenever any particular description of traffic was brisk, bodies, to suit the traffic, might be mounted on the available frames and wheels. In this way, a line could have as large a carrying power as at present, with a considerable reduction in first cost of vehicles.

A method of working similar to this is in use on the Eisenerz Railway in Styria, on which vehicles, running on portions of the line with easy gradients, are sent up and down the inclines at the Eisenerz mines, on frames built for running on inclines only.

However this method of working seems to be chiefly of importance, because it enables the transhipment of goods in through traffic between broad and metre gauge lines to be dispensed with.

Since a metre gauge covered goods wagon takes five tons, or exactly half the load of a full sized broad gauge wagon; it is plain that, by using axles a little stronger than those in ordinary use in broad gauge vehicles, it will be possible, at junctions, to run two loaded metre gauge wagons on to each set of broad gauge wheels available, by putting a light frame, carrying two pairs of rails for metre gauge wagons, on to the broad gauge wheels. When traffic offers at broad gauge stations for the metre gauge line, the consignments will have of course to be loaded in metre gauge wagons obtained for the purpose. It will be necessary to provide platforms carrying light metre gauge rails to enable metre gauge vehicles to be run on to or off from the broad gauge frames.

The accompanying drawing shows a pair of metre gauge wagons mounted on a broad gauge frame. It will plainly be necessary to make the metre gauge vehicles of the same length as broad gauge vehicles, and at the same time to reduce the width of the metre gauge vehicles to about five feet. The metre gauge wagons when on the broad gauge frames are prevented from shifting by double-headed hooks catching two eyes on the ends of the metre gauge wagons as shown at *Fig.* 3. The double-headed hooks are secured to the ends of the broad gauge frames, and can be opened or tightened up by screwing up or unscrewing nuts on the lengths of screw thread at the ends of the hooks.

The broad gauge frames used for through traffic with a metre gauge line can be provided with moveable bodies, so as to work as broad gauge vehicles when not required for through traffic. Doubtless some few difficulties will be found in starting a system of this sort; but no difficulties of a formidable nature are likely to arise.

It is plain that if this method of working can be introduced, it will do away with the most formidable objections which now exist to the use of the metre gauge for branch lines.

To reduce the dead load of vehicles with this system, it would be well to make the bodies of metre gauge wagons moveable. The bodies alone of the metre gauge wagons would then be sent on to the broad gauge line.

W. S.

METHOD OF AVOIDING TRANSHIPMENT OF GOOD IN THROUGH TRAFFIC.

Scale. 1 inch = 6 feet.

FIG. 3.

END ELEVATION OF A BROAD GAUGE FRAME LOADED WITH 2 METRE GAUGE WAGONS

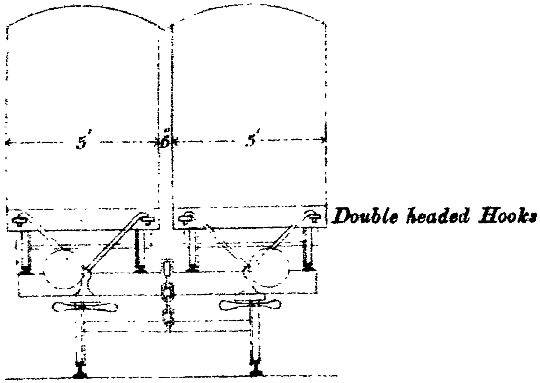


FIG. 1.

SIDE ELEVATION OF A BROAD GAUGE FRAME LOADED WITH METRE GAUGE WAGONS

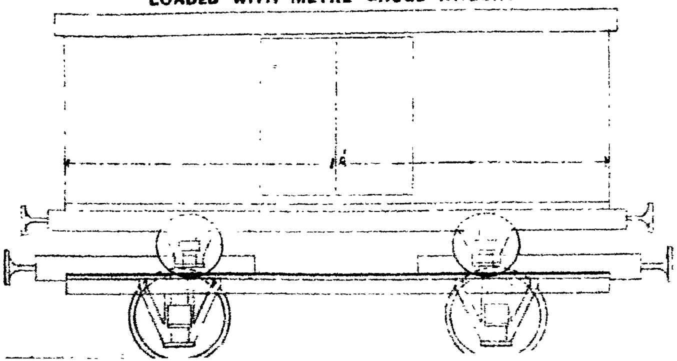
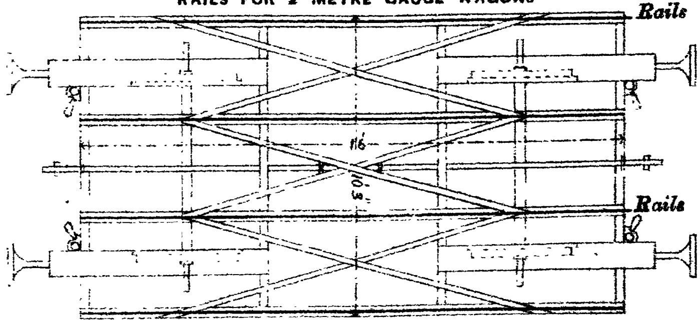


FIG. 2.

PLAN OF A BROAD GAUGE FRAME WITH RAILS FOR 2 METRE GAUGE WAGONS



No. CCXCIII.

DESCRIPTION OF A PLAN FOR FACILITATING THE CONSTRUCTION OF THE STEINING FOR WELLS.

Plate.]

By W. Bull, Esq., *Assoc. Inst. C.E.*

By all who have had experience in well building and sinking, it will have been noticed what constant care is necessary to keep the masonry of a well truly cylindrical. This is more difficult as a well gets out of the perpendicular, which at some period happens to nearly every well sunk. This can be almost, if not entirely, obviated, and an absolutely true circle of the same radius be ensured by the use of a cylindrical templet, of a diameter equal to the outer diameter of the well, and inside which the brickwork is to be built. This plan was first designed for, and used in, the construction of Irrigation wells, with a view to facilitating the building simultaneously with the sinking. With dredgers or moats coming out constantly, it is very difficult for a mason to use either templets or straight-edges as applied by hand. With the cylindrical templet neither of the above or any plumbing is required.

In construction the templet will be as shown in the accompanying Plate.

For a larger sized well the parts should be proportionately heavier.

The cylindrical templet can be used in two ways. First—on starting the brickwork of a well it should be placed on the curb, which in nearly all cases is of a slightly greater diameter than the brickwork is intended to be. Four courses can then be built. The templet is then to be raised six inches, and supported in four places by a flattened nail driven in between the 2nd and 3rd courses. Two more courses are then to be built, and the templet raised as before, and so on regularly. The planes of the courses being parallel, the outer face of the brickwork *must be* parallel to the axis of the well, whether the latter be perpendicular or not.

The accuracy with which a cylinder can be built with this templet is really astonishing, and the masons take to it at once with the greatest readiness.

The second method of using it is more applicable to Irrigation wells built with radiating bricks without mortar. By means of it the building and sinking can be carried on together. We will suppose then a length of say 20 feet was built in accordance with the first method, and sunk till the top is on a level with the ground. A course of bricks should then be laid with a rise equal to the thickness of one course in one circumference. A wooden frame should be constructed exactly like a door frame, only square, large enough to fit freely on the outside of the well. This should be firmly supported and fixed, resting on the ground or some way free from the masonry of the well, in the same plane as the top of the well before the sloping course was put on. The cylindrical templet rests on this. As the well sinks the casing can be built in the spiral endless course which results from the sloping one. The saving in labour by this method is very great. Any smart coolie can lay the bricks, and it is difficult for him to do it incorrectly. The saving in time by working on this principle is so great, that an Irrigation well, which, if the bricks are well burnt, gives as permanent a job as can be desired, can be easily sunk in ten days to a depth of 50 feet.

The object of the spiral course is to save all cutting, as it is almost impossible, owing to irregularity of shrinkage of the bricks, both in drying and burning, to get them sufficiently accurate in shape, to enable a course to be formed with a fixed number. A few half bricks should be prepared to break joint when it may be necessary.

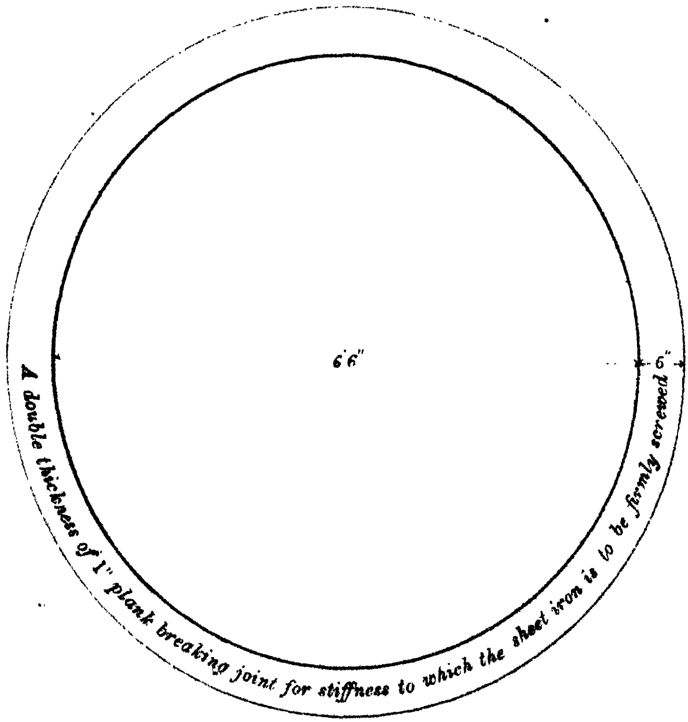
The method resulting from the use of the templet and spiral course, although wood has been successfully worked, but the writer would be much obliged if persons trying the plan would communicate to him their success.

W. B.

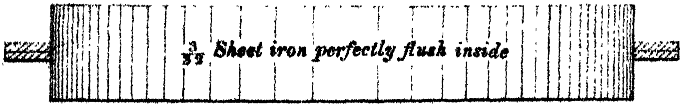
DESCRIPTION OF A PLAN FOR FACILITATING THE CONSTRUCTION OF THE STEINING FOR WELLS.

Scale. 1 inch = 2 feet.

PLAN



SECTION



No. CCXCIV.

ON THE WEIGHT OF A PACKED CROWD OF NATIVES.

By W. A. Francken, Esq., *Depy. Supdt. Roorkee Workshops.*

On the 9th of February, 1876, I made the following observations on the weight of a packed crowd of natives.

I put 102 beldars employed at the Workshops in a room measuring 9 feet 2 inches by 9 feet. The men were selected at random without reference to weight, but only adults were taken.

The men were allowed to pack themselves, no extraneous force being used, so that the conditions were such as might occur in a crowd.

The results were as follows :—

Number of men packed, ...	=	102	
Space in which packed, ...	=	82·5	s. ft.
Total weight 141 mds. 29 srs. 8 chts., at 82·285 lbs. per md.,	=	11663·08	lbs.
Weight per superficial foot, ...	=	141·37	„
Average weight of each man, ...	=	114·34	„
Maximum do. do., ...	=	139·88	„
Minimum do. do., ...	=	93·80	„

W. A. F.

February 9th 1876.

No. CCXCV.

THE "CHIN CHIA" OR CHINESE CHAIN-PUMP IN THE LARUT TIN MINES.

[*Vide* Plate].

BY P. DOYLE, ESQ., C.E., F.S.S., M.R.A.S., *Superintendent Public* *'s, Surveys, and Mines, Perak.*

THE mines are quarries or entirely open excavations, from 10 to 25 feet deep, through comparatively porous soils, and the spring level of the country being only six feet below the surface of the ground, the percolation of water into the workings is very great indeed, due chiefly to the high rainfall, which averages 150 inches, distributed pretty evenly throughout the year, and the numerous water-courses intersecting the mines, which are required for turning the water-wheels working the pumps engaged in draining.

The following description will, it is anticipated, sufficiently explain the accompanying diagrams, affording all needful information anent the arrangement and details of the different parts of the machine.

The chain-pump in use by the Chinese in the Larut mines is only a modification of appliances long known in Europe and the East. It consists of a wooden gutter or working barrel, placed at an angle which seldom exceeds 20°. A fair average of the existing grades is 1 in 6. The gutter or trough is from 12 to 16 inches high, and from 4 to 6 inches wide, and of lengths ranging up to 100 feet, composed of three *single* planks. A few inches above, and supported by framing attached to the sides, a fourth plank or platform runs for the full length parallel to the trough. An endless wooden chain, with wooden blades, about one foot apart, on each side of the link, is exactly fitted to, and works in, the wooden channel, passing over two pulleys, or, more correctly, sprocket wheels, one at the upper, and one at the lower, end. The upper pulley is on the axle of an overshot water-wheel, driven from the tail race of the mine higher up, or directly from the head race, and the pulley at the lower end of the pump, which is submerged, guides the blades which travel down the platform and up the trough, the water drawn up by the floats being discharged into a channel at the head. Breaks are also provided to prevent a retrograde or downward motion of the blades, and the serious consequences in the trough in the event of the chain separating, or the stream of water in the overflow or shoot being suddenly shut off. In some of the smaller workings the pump is worked by coolies, by means of a treadmill on the shaft of the upper pulley, and in a few instances formerly buffaloes are said to have been the motive power.

The water-wheels in the Larut mines (some 84 in all) are from four to five feet diameter, and from two to three feet breast. The fall at each pump, its lift, and performance vary, and the following are the means deduced from six pumps selected indiscriminately, the measurements being taken on a morning succeeding a night of heavy rain, when the wheels were working under favourable conditions:—

Fall, $5\frac{1}{3}$ feet;
Lift, $13\frac{1}{2}$ „
Discharge, per minute, 6·36 cubic feet;
„ per hour, 2,385 gallons;
Ratio $\frac{\text{Effect}}{\text{Power}}$ = ·22, or between $\frac{1}{5}$ and $\frac{1}{4}$;
Trough, inclination, $9\frac{1}{2}°$;
„ length, 87 feet.

An example would, perhaps, better illustrate the foregoing description and results.

Fall = $5\frac{1}{3}$ feet;
Lift = 25 feet;
Discharge of overfall or shoot = $2\frac{1}{2} \times \frac{1}{2} \times 2\frac{1}{2}$ (velocity),
= $3\frac{1}{8}$ cubic feet per second.

The wheel made $\frac{1}{3}$ revolution per second, and each revolution corresponded to 6 blades of the pump, so that $\frac{1}{3} \times 6 = 2$ blades were discharged per second.

Discharge per blade $= 1 \times \frac{1}{3} \times \frac{1}{4} = \frac{1}{12}$ cubic feet;

" of pump $= \frac{1}{12} \times 2 = \frac{1}{6}$ cubic feet per second.

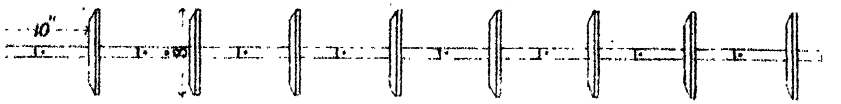
The effective work done was, therefore,

$$\frac{\frac{1}{6} \times 25}{3\frac{1}{8} \times 5\frac{1}{3}} = \frac{1}{4} \text{ of the power employed.}$$

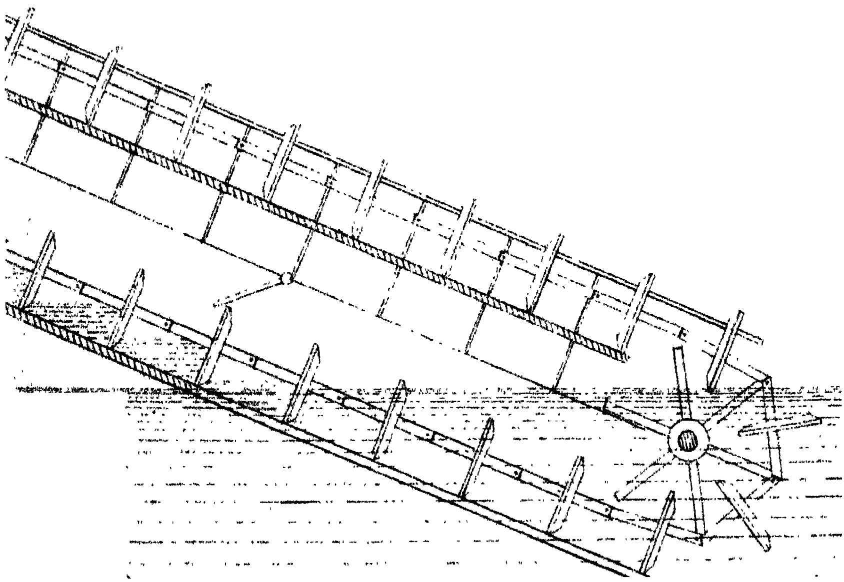
This is about *a third* of what would be obtained were the same power applied to a centrifugal pump. The waste of power is no doubt due to the very great friction necessitated by the construction of the machine.

P. D.

CHAIN LINKS AND BLADES END ELEVATION



PLAN



No. CCXCVI.

NOTE ON EXPERIMENTS ON STRENGTH AND ELASTICITY OF ASINA TIMBER.

BY G. R. BIRD, ESQ., *Exec. Engineer.*

Asina tree (*Terminalia Tomentosa*), also called the Hasna, Arsena or Asan, grows in great abundance in the forests of the north of Oudh. It was used by the natives, in the King's time, for roofing purposes, as is testified by its existence in some of the old buildings at Lucknow. From annexation the demand practically ceased, owing to the cheapness of sal timber, imported from Nepal, and to the supposed untrustworthy character of Asina and its liability to be attacked by dry rot. The increasing scarcity and consequent high price of sal eventually brought Asina again into request, and since 1871 it has been very generally used throughout the province for temporary and semi-permanent buildings. It is moreover likely to retain its position as a second class timber, and as there are no published data relating to its ultimate strength or elasticity, (the Roorkee Treatise being also silent on the subject,) some rough experiments were made in 1877, and the results obtained therefrom may be found useful, till they are superseded by more reliable information derived from a greater number of trials.

The pieces experimented upon, five in number, were taken at random from among a quantity of battens sawn up for a building then in process of construction. They were planed down to a uniform section, and successively placed on two supports and weighted in the usual way. The various observations were recorded in a table, *see* page 67.

Very little time could be spared for these experiments, owing to an unusual pressure of work, and hence the successive increments of weight were larger than should be imposed in delicate operations of this nature, but in every other respect great care was taken to produce a reliable series of results. It may be due to this rapid loading that piece No. 2 failed so suddenly when only two-thirds of the breaking weight had been applied, or it may be an example of the inherent unreliable quality of this wood itself, for in appearance and treatment there was no visible difference between the pieces experimented on.

The rough quality of the apparatus employed caused sundry interruptions during the time the first piece was under trial, and it is probable that this piece would have borne as great a weight as No. 3 had it not been crippled by the frequent removal of the scales. In the deductions given below, the breaking weight assumed is for this reason fixed higher than the actual results obtained from No. 1 would otherwise warrant.

It is believed that the following data derived from these experiments give a very fair idea of the strength and elasticity of this timber, and that the scantlings of roof timbers calculated from the coefficients will be found amply strong enough.

I. Ultimate breaking weight under transverse strain, or p_b Roorkee Treatise = 640 lbs. per square inch.

II. Modulus of Elasticity, E_d of the Roorkee Treatise = 4,150.

III. Formula for calculating breadth of scantling from deflection $b = \sqrt[4]{L^2 W \times \cdot 0021}$; where $d = b\sqrt{2}$

The results obtained by using this last formula are somewhat higher than the scantlings derived from the ultimate weight.

NOTE.—Roorkee Treatise Notation employed throughout.

Detail of Experiments on Transverse Strength of Asina timber, conducted at Pertabgurh on the 6th of May 1877.

Dimensions of Piece: Bearing	Breadth	Depth	Weight applied, in lbs.	Deflection in inches	Breaking weight per square inch deduced by $p_b = \frac{LW}{bd^2}$	Remarks
3'	$1\frac{1}{2}$"	2"	270	$\frac{14}{48}$	624 lbs.	Piece No. 1. Weight in the middle.
			360	$\frac{18}{48}$		Structure slightly knotty.
			450	$\frac{22}{48}$		
			540	$\frac{25}{48}$		
			630	$\frac{31}{48}$		
			720	$\frac{35}{48}$		Scale touched the ground, weight removed, permanent set found to be $\frac{6}{48}$".
			810	$\frac{41}{48}$		
			900	$\frac{45}{48}$		Rope broke, weight removed, set $\frac{9}{48}$".
			983	$\frac{53}{48}$		
			1,069	$\frac{61}{48}$		Rope again broke, weight removed, set $\frac{12}{48}$".
			1,159	$\frac{71}{48}$		Horizontal cracks appeared about 6 inches on each side of centre, but these closed up soon afterwards; sound of cracking heard.
			1,249	...		Piece broke soon after application of this weight.
3'	$1\frac{1}{2}$"	2"	347	$\frac{18}{48}$	440 lbs.	Piece No. 2. Weight in the middle.
			437	$\frac{22}{48}$		Very even grain throughout.
			659	$\frac{30}{48}$		
			881	...		Piece collapsed suddenly without warning.
3'	$1\frac{1}{2}$"	2"	317	$\frac{14}{48}$		Piece No. 3. Weight in the middle.
			407	$\frac{19}{48}$		Very even grain throughout.
			629	$\frac{25}{48}$		
			851	$\frac{35}{48}$		
			926	$\frac{38}{48}$		

Dimensions of Piece			Weight applied, in lbs.	Deflection in inches	Breaking weight per square inch deduced by $r_b = \frac{LW}{bd^2}$	Remarks
Bearing	Breadth	Depth				
3'	$1\frac{1}{2}''$	2"	1,001	$\frac{41}{48}$	643 lbs.	Piece No. 3 (*Continued*).
			1,076	$\frac{47}{48}$		
			1,151	$\frac{51}{48}$		
			1,196	$\frac{58}{48}$		Slight crack at upper edge, horizontal, 6 inches from centre.
			1,241	$\frac{58}{48}$		
			1,271	$\frac{62}{48}$		Cracked across the centre on the lower side and splintered back each way.
			1,286	...		Collapsed.

By Deflection.

Dimensions of Piece			Weight applied, in lbs.	Deflection in inches	Modulus of Elasticity deduced by $\delta = \frac{5}{8} \frac{L^3W}{E_d bd^3}$		Remarks
Bearing	Breadth	Depth					
5'	$1\frac{3}{8}''$	2"	39	$\frac{4}{48}$	Taking safe deflection at $\frac{1}{480}$ span or $\frac{1}{8}''$. $E_d = 4{,}091$	$b = \sqrt[4]{L^2W} \times \cdot 00216$	Piece No. 4. Weight uniformly distributed.
			72	$\frac{6}{48}$			
			104	$\frac{8}{48}$			Weight removed and specimen recovered its straightness.
			130	$\frac{9}{48}$			No permanent set noticeable.
5'	$1\frac{7}{16}''$	2"	39	$\frac{3}{48}$	$E_d = 4{,}239$	$b = \sqrt[4]{L^2W} \times \cdot 00209$	Piece No. 5. Weight uniformly distributed.
			78	$\frac{6}{48}$			
			117	$\frac{9}{48}$			
			130	$\frac{12}{48}$			Weight removed and specimen recovered its straightness. Weight again applied for 8 hours and on removal beam recovered ; no permanent set appreciable.

21st January, 1879. G. R. B.

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CONTENTS.

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The articles now in hand are—

1. Mysore Cultivation and Irrigation. By Major Fraser, R.E.
2. Solid Iron Pile Bridges. By Lieut.-Col. C. A. Goodfellow, R.E.
3. Helical Cutter for Well sinking. By E. W. Stoney, Esq.

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A. M. B.

No. CCXCVII.

THEORY OF THE BRACED ARCH—INDUS BRIDGE AT SUKKUR.

[Vide *Plates* I.—V.]

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

CONTENTS.

Chapter I.

Chapter II.—Stresses in Braced Arch.

Chapter III.—Application to Indus Bridge of Theory of Chap. II.

PREFACE.

The following Paper contains the author's calculations of Stresses in the main parts of a large steel arch bridge proposed for the river Indus at Sukkur, designed by Mr. G. L. Molesworth, C.I.E., (Consulting Engineer for State Railways,) of 740 feet span, and 200 feet rise.

The complete Bridge consists virtually of two Bridges, a Road-Bridge, and a Railway-Bridge side by side, 66 feet apart from centre to centre, with the platform of each *suspended* from and between a pair of steel arched Ribs, 22 feet apart from centre to centre.

Each Rib is divided into equal semi-Ribs, meeting in a *free joint* at the crown, and each semi-Rib abuts upon a *free joint* at the abutments. The Thrust of the Arch is resisted entirely by the abutments, (which are rock,) and not at all by the platforms, which are designed simply as a roadway and a railway on *light* longitudinal Girders.

Each semi-Rib consists of a pair of parallel square steel tubes each 2′ × 2′ from out to out, one over the other, 22 feet apart from centre to centre, connected together by cross bracing which divides the semi-Rib into Bays of 22 feet length.

A skeleton elevation of one semi-Rib (without the platform) is given in *Plate* III., (which also shows the proposed mode of erection,) and a cross-section of one of the square steel tubes in *Plate* V.

The pair of Ribs carrying one track are united by cross-bracing, and both the two platforms and also the two inner Ribs of each track are united by cross-bracing. The pair of Bridges thus form together a single Bridge of very wide Bridge-Base (88 feet), and therefore possessing great lateral stiffness for resisting wind, which is necessary on account of the great height of the Structure.

The present Paper is intended to show only the principles and mode of calculation of the Stresses in the Structure. This alone is the present writer's work. The Design itself is Mr. Molesworth's.

CHAPTER I.—INTRODUCTION.

1. Certain parts of the Theory of the Braced Arch, and certain formulæ based thereon having been found to be *incorrect* in some of the published authorities, especially in the *formulæ relating to unsymmetric Load*, it has been thought necessary to precede the present calculations of Stresses in the proposed Indus Bridge Steel Arch by a preliminary mathematical investigation of the principles on which the Theory is based, and of the formulæ resulting which are to be used in the calculations, as these formulæ differ from those given in several authorities.

The mathematical portion of what follows is really very simple, as from the mode of hinging the Arch at the crown and at both springings, it can be treated entirely by elementary Statics: had it not been so hinged, this elementary method would have failed. This mathematical work occupies Chap. II.

Chap. III. contains the application of the principles and formulæ of Chap. II. to the case of the Indus Bridge: the Method employed being the Graphic Method, which has the advantage of showing most of the Results to the eye.

Chap. IV. contains the mathematical investigation of the effect of the Wind on the Arch followed by application to Indus Bridge.

Chap. V. contains an investigation of the Stresses in the Stays during the erection of the Arch, and of the effect of the Wind.

All heavy numerical calculations have been collected together into a series of Sheets forming Chap. VI. All the numerical work, and scaling off the Diagram E, has been carefully checked by an independent computer.

* *Given in the Discussion following M. Gaudard's Paper on "Construction of Metal and Timber Arches," Paper No. 1221 in Vol. XXXI. of "Proceedings of Inst. of Civil Engineers," 1870-71.*

CHAPTER II.—STRESSES IN BRACED ARCH.

2. It is convenient to premise the following definitions :—

NEUTRAL CURVE OF RIB.—This is the curve traversing the centres of gravity of all *normal cross-sections* of the Rib.

FUNICULAR POLYGON.—This is the polygon which is *balanced* under vertical Loads applied at its angular points, so that the Stresses produced lie wholly along the sides of the polygon, and there is *no tendency to distortion of the polygon.*

CURVE OF EQUILIBRIUM.—This is the curve to which a funicular polygon approximates as the Loads increase in number and decrease in distance apart, tending in fact towards continuous load.

For every given system of Load, there is a definite "Funicular Polygon" whose vertices lie on the verticals through the (centres of gravity of the) several given Loads, with no tendency to distortion.

If the "Neutral Curve" of a given Rib coincide with the "Funicular Polygon," or "Curve of Equilibrium" of a given system of Load, there will be *no tendency to bend* or distort the Rib under that Load, and the Stresses produced will be wholly perpendicular to its normal sections, *i.e.*, will be *simple Thrusts* upon its cross-sections. This is the most favourable possible condition, *towards which it is therefore desirable to approximate.* In this case, if

T = Total Thrust across any cross-section,

A = Area of that cross-section,

s_c = Safe crushing stress-intensity = 6·5 *tons per sq. in.* for steel,

then A may be found by the simple formula,

$$A = \frac{T}{s_c}, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

But under varying Load, it is impossible that the Neutral Curve of a given Rib should coincide with the Curves of Equilibrium of all states of the Load, because the Curves vary when the Load varies. In this case a bending action is introduced in all cases of non-coincidence of the Equilibrium-Curve with the Neutral Curve, increasing with the amount of separation of the two Curves.

This causes additional longitudinal Stress perpendicular to the normal cross-sections of the Rib, to be calculated precisely as in ordinary cases of Transverse Strain, *viz.*, from the Bending Moments (M), and also a shearing Stress (F) parallel to the normal cross-sections of the Rib.

The above longitudinal Stress falls principally on the Flanges of the Rib, so that their sectional area depends jointly on the Total Thrust (T) above-mentioned, and on the additional longitudinal Stress due to the bending action: and falls under the Rules laid down in Chap. XIII. of the Author's Manual of Applied Mechanics.

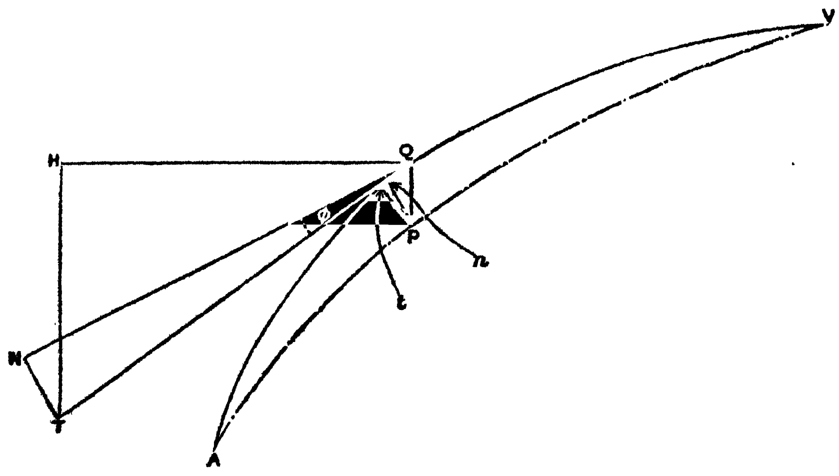
The Shearing Stress (F) falls principally on the Braces (between the Flanges); the Stresses (R) in the Braces may be calculated from the Shearing Force (F) as explained in Chap. X. of same Manual, *viz.*, by the formula

$$R = F \operatorname{cosec} i, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2),$$

where i = inclination of the Brace to the "neutral curve" of Rib.

[*N.B.*—There will be a further *partial* Shearing Stress *falling on the Braces* due to the mode of attachment of the Load to the Rib, but as this is not cumulative, it is not thought worth investigation; the Stress in the Braces of any one Bay—due to this cause—being *only that due to the partial Load on that Bay*, and to the Braces being the connectors which distribute that Load between the Flanges].

Properties of Equilibrium-Curve
[under vertical Load].



3. Let APV be the Neutral Curve of a Rib.

AQV be the Equilibrium-Curve for a given system of vertical Load.

P, Q corresponding points on the two curves, *i.e.*, on same vertical QP.

Draw QT tangent to the Equilibrium-Curve at Q.

QN parallel to the tangent to the Neutral Curve at P, (and therefore perpendicular to the normal section P*n* of the Rib at P).

P*t*, P*n* $\perp^r$ to QT, QN, respectively, to meet QT in *t*, *n*, respectively.

The Resultant of all the Forces to the right of Q is necessarily—by the property of the Equilibrium-Curve—a certain Resultant THRUST through the point Q in the direction of the tangent QT to the Equilibrium-Curve, which may be represented by QT, or shortly by T.

Draw QH horizontal, TH vertical, TN $\perp^r$ to QN.

Let $Pt = \delta$, $Pn = n$, $QP = v$.

Then by elementary Statics, it is clear that QT is equivalent to QH, HT *applied at* Q, whereof,

QH, (or H) is the HORIZONTAL THRUST at Q, and is—by the property of an Equilibrium Curve—a *constant quantity* right round the curve, ... (3).

HT, (or W) is the algebraic sum of vertical Forces to right of Q,.. (4).

Again by elementary Statics, it is clear that, with respect to the normal section P*n* of the Rib, the Resultant Thrust QT (or T) is equivalent to the pair QN, NT *applied at n*, whereof,

QN, (or N) being $\perp^r$ to the cross section P*n*, and applied at a distance = P*n* (or *n*) from its centre of gravity P, is equivalent in effect on that cross-section to a Thrust QN (or N) *applied uniformly all over that section*, together with a Bending Couple whose Moment is QN . P*n*, (or N . *n*), ... (5).

NT, (or F) being ∥ to the cross-section Pn and applied at a point n in its plane is a simple Shearing Force in that section, ... (6).

It is clear then that the Direct Thrust (N) along the Rib, and the Shearing Force (F) across the Rib, are the resolved parts of QT or T ∥ and ⊥ʳ to the tangent to the Rib.

Now in many of the cases of practice, the angle $N\hat{Q}T$ (or ϕ) between the tangents to the Equilibrium-Curve and the Rib at QP, is a small angle, so that its cosine is nearly 1. Hence N, F are given by

$N = T\cos\phi$, *accurately*,... (7).

$= T$, *approximately*, whenever ϕ is a small angle,......(8).

$F = T\sin\phi$, ... (9).

Again, from the equality of the angles $T\hat{Q}H = Q\hat{P}t$, $T\hat{Q}N = t\hat{P}n$, it follows that $\frac{H}{T} = \frac{\delta}{v}$, and $\frac{N}{T} = \frac{\delta}{n}$,................(10).

Hence the Bending Moment (M) above explained to be equal to $N \cdot n$ is given by any of the expressions

$M = H \cdot v = T \cdot \delta = N \cdot n$, ... (11).

[The first expression $M = H \cdot v$ is very convenient when M has to be calculated for many points, because its first factor (H) is *constant*, and the second (v) is more easily measurable or calculable than δ or n].

CALCULATION OF FLANGE-AREAS

[for a symmetric cross-section].

4. It has been explained that the cross-section is subject to—

(1) a Direct Thrust (N) uniformly distributed over its area (A),

(2) a Bending Couple of Moment M.

The effect of the latter is known to be a uniformly-varying stress over the cross-section of the Flanges.

Let s_c = maximum mean crushing stress-intensity admissible in the Flanges.

p_o = uniform crushing stress-intensity developed by the Direct Thrust (N) alone.

$\bar{y}$ = distance of centre of gravity of either Flange from the neutral curve.

y_r = radius of gyration of the cross-section about its neutral axis.

p_y = mean stress-intensity developed in either Flange by the bending action alone.

y' = half depth of cross-section.

Then the condition of working strength is

$$s_c = p_o + p_y, \dots\dots\dots\dots (12).$$

But
$$p_o = \frac{N}{A}, \dots\dots\dots\dots (13).$$

And by the ordinary Theory of Transverse Strain,

$$p_y = \frac{M}{A \,.\, y_r^2} \,.\, \bar{y}, \dots\dots\dots\dots (14).$$

Combining the above,

$$s_c = \frac{N}{A} + \frac{M}{A \,.\, y_r^2} \,.\, \bar{y}, \dots\dots\dots\dots (15).$$

whence
$$A = \frac{N}{s_c} + \frac{M \,.\, \bar{y}}{s_c \,.\, y_r^2}, \textit{ accurately}, \dots\dots\dots\dots (16).$$

$$= \frac{T}{s_c} + \frac{T \,.\, \delta}{s_c \,.\, y'}, \textit{ approximately}, \dots\dots\dots (17).$$

because $N = T$ approximately, and $\bar{y} = y' = y_r$, approximately, (18).

$$\therefore A = \frac{T}{s_c} \,.\, \left(1 + \frac{\delta}{y'}\right), \textit{ approximately}, \dots\dots\dots (19).$$

This Result may also be exhibited in such a form as to show the Area required to resist the bending action in terms of that required to resist the Direct Thrust alone. Thus—

Let A_1 = Area required to resist the Direct Thrust alone.

A_2 = Area required to resist the Bending action alone.

Then
$$A = A_1 + A_2, \dots\dots\dots\dots (20).$$

And
$$A_1 = \frac{N}{s_c} = \frac{T}{s_c} \text{ (approximately)}, \dots\dots\dots (21).$$

Hence subsituting into Eq. (19),

$$A = A_1 \,.\, \left(1 + \frac{\delta}{y'}\right) = A_1 + A_1, \dots\dots\dots\dots (22).$$

whence
$$A_2 = \frac{\delta}{y'} \,.\, A_1, \textit{ approximately}, \dots\dots\dots\dots (23),$$

a very convenient expression for calculation of A_2.

[The error consequent on use of this formula will be investigated hereafter, Art. 11.]

To draw an Equilibrium-Curve.

5. When the Loads form a detached system, the curve becomes a "funicular polygon". When the *positions* of vertical lines through the centres of gravity of the several Loads are given, and when also *three* points in the curve (*e.g.*, the crown and both springings) are given, the Problem is a determinate Problem of "*elementary Statics*", but **not otherwise.*

These three points, the crown and the two springings may be considered given when *all three are perfectly* hinged,* so as to be incapable of resisting distortion, and the rise and span are also given.

The following then is a determinate Problem of elementary Statics:—

"Given the rise (k) and span ($2c$) of the Neutral Curve of a Rib "hinged at the crown and at both springings, also the positions of "the centres of gravity of the several Loads on the Rib, to draw "the Equilibrium-Curve."

The first Step is to determine the tangents at the crown: this is most conveniently done by calculating the vertical heights y', y'' at which these tangents meet a pair of vertical lines through the springings.

Let W′, W″ be the Total Loads on right and left semi-arches.

$\bar{x}'$, $\bar{x}''$ be the horizontal distances of verticals through the centres of gravity of W′, W″ from the right and left springings, respectively.

Then the Horizontal Thrust (H) may be shown to be, (*see* Art. 10)

$$H = \frac{W'.\bar{x}' + W''.\bar{x}''}{2k}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24).$$

Also it may be shewn that, (*see* Art. 10)

$$y' = \frac{W'.\bar{x}'}{H}, \quad y'' = \frac{W''.\bar{x}''}{H}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (25).$$

By plotting these lengths ($A'k' = y'$, $A''k'' = y''$ in figure) the tangents may be at once drawn.

* If not perfectly hinged at all three points, if for instance *continuous at crown*, the Problem becomes a problem of some complexity, *not solvible by elementary Statics:* the elastic deformations would have to be considered, and the calculations involved would be *very laborious.*

[Of course $y' + y'' = 2k$; this forms a check on the calculation of y', y''].

There are two cases in which the tangents at crown form a *horizontal* straight line, *viz.*,

(1), when the Loads are symmetric about the crown; this case is obvious;

(2), when the Loads are so arranged that $W'.\bar{x}' = W''.\bar{x}''$, for then $y' = y''$.

The quantities $W'.\bar{x}'$, $W''.\bar{x}''$ may be conveniently calculated as follows:—

Let w′, w″ be any Loads on right and left semi-arch, respectively.

x', x'' the distances of their centres of gravity from right and left springing, respectively.

Then

$$W'.\bar{x}' = \Sigma_{x'=0}^{x'=c} w'.x', \quad \text{.................. (26a).}$$

$$W''.\bar{x}'' = \Sigma_{x''=0}^{x''=c} w''.x'', \quad \text{..................(26b),}$$

the summation being effected throughout either semi-arch, *i.e.*, from x' or $x'' = 0$ to c, (where c = semi-span).

The tangents at crown having been drawn, the Equilibrium-Curve may now be drawn either (1) by calculation of the vertical depression (y) of each point P below these tangents, or (2) by a graphic construction.

6. METHOD 1°. *By calculation*—

Let W = Total Load between crown and any point P in the funicular polygon.

$\bar{x}$ = Distance of a vertical through the centre of gravity of the above Load W from the (variable) point P.

y = Vertical depression required of the point P below the tangent at crown.

Then, it may be shewn that

$$y = \frac{W.\bar{x}}{H}, \text{ (see Art. 10), ...(27).}$$

7. METHOD 2°. *By graphic construction.*—The Method will be described as for a Semi-Arch, suppose the left Semi-Arch VA″.

Plot the points showing the crown V and springing A″ for the given semi-span A″M and rise VM, and draw verticals 1, 1′; 2, 2′; 3, 3′; 4, 4′; 5, 5′ through the centres of gravity of the given Loads.

Plot the tangent VT at the crown V for that system of Loads, by setting off the (already calculated) height A″*k* or $y'' = \frac{W' . \bar{x}'}{H}$ at which it meets the vertical A″*k* through A″.

Draw a vertical line *m*G at the distance (already calculated) A″*m* or $\bar{x}'' = \frac{\Sigma_o^c wx'}{W''}$ which defines the horizontal distance of the centre of gravity of the Load W″ on the Semi-Arch from the left springing. Suppose this line *m*G to meet VT in G.

[This point G will be found to be the pole from which the Thrust-lines to be presently drawn radiate].

Through G draw a horizontal line G*t*, and on it take G*t* to represent on any scale the Horizontal Thrust $H = \frac{W' . \bar{x}' + W'' . \bar{x}''}{2k}$, (already calculated,) due to the given Load-system (W′ + W″); and through *t*, its further end, draw T*te* vertical meeting the tangent VT in T, and take T*e* downwards thereon to represent the Total Load W″ on the semi-arch on the same scale: this line T*e* will be called the "Load-line".

[It is convenient to choose the scale, so that the vertical line T*e* shall fall well clear, *i. e.*, to left of the vertical A″*k*].

Join G*e*. This line will represent the Thrust at the springing A″, and GT will represent the Thrust at the crown.

[The line G*e* last drawn should pass through A″. This is a check on the accuracy both of the numerical work on which the drawing is based, and of the drawing itself].

Divide the Load-line T*e*, beginning from T, into segments T*a*, *ab*, *bc*, *cd*, *de* representing the several Loads on the semi-arch taken in order from the crown towards the springing, *viz.*, in the lines 1, 1′; 2, 2′; 3, 3′; 4, 4′; 5, 5′.

Join G*a*, G*b*, G*c*, G*d*. The several radiators GT, G*a*, G*b*, G*c*, G*d*,

Ge, represent the Thrusts in the "funicular polygon" V12345A″ (about to be drawn), *viz.*, in the several lines V1, 1 2, 2 3, 3 4, 4 5, 5A″.

Last Step. To draw the "funicular polygon".

Point 1. The tangent VT through the crown cuts the vertical 1, 1′ through the Load next the crown in the point 1 required.

Point 2. A parallel to G*a* through the point 1 (just found) will cut the vertical 2, 2′ through the second Load from the crown in the point 2 required.

Point 3. A parallel to G*b* through the point 2 (just found) will cut the vertical 3, 3′ through the third Load from the crown in the point 3 required.

Points 4, 5. The remaining points are to be similarly found.

Result. The figure V12345A″ is the "funicular polygon" proper to the given Load-system (W′ + W″).

Check on the work. The last point but one, *viz.*, the point 5 in present figure, should fall on the (already drawn) tangent GA″.

Another mode. The construction may—if preferred—be started from both ends V, A″ at once: in this case the two branches ought to meet at some intermediate point, which affords a check on the drawing.

8. USE OF THE DIAGRAM.—The chief use of the Diagram is for finding the three quantities N, F, δ required for calculation of Stresses in, and sectional areas of, the Flanges and Braces.

Draw the "Neutral Curve" V*a*′*b*′*c*′*d*′*e*′A″ of the Rib; and draw *a*′*m*, *b*′*n*, *c*′*n*, *d*′*n*, *e*′*n*, perpendicular to the several sides of the "funicular polygon" V12345A″.

Then these lengths *a*′*m*, *b*′*n*, &c., are the departures of the points of the "Neutral Curve" of the Rib, above denoted by δ, required for finding that part of the sectional areas of the Flanges (*viz.*, A_1) required to resist distortion.

Next draw the tangents (or normals) to the Neutral Curve of the Rib at all the points V, *a*′, *b*′, *c*′, *d*′, *e*′, A″. The resolved parts of the Stresses or Thrusts (T) in the Equilibrium-Curve represented by the radiators GT, G*a*, G*b*, &c., from G, taken parallel and perpendicular to the several tangents just drawn, are the required Direct Thrusts (N) and Shearing Forces (F) over the normal sections of the Rib.

But in all cases when the Neutral Curve of the Rib and the Equilibrium-Curve are only slightly inclined to one another, the Thrusts (T) in the latter (represented by the radiators from G) are sensibly the same as the required Direct Thrusts (N) in the former, and may therefore be taken for them.

Thus the three required quantities N (or T), F, δ are easily obtained from the Diagram.

Effect of travelling Load.

9. When the Load varies,—covering for instance different lengths of, and also different portions of, the Span—the Equilibrium-Curve changes *in shape and position.*

Now from the expressions given for the Flange-areas, and Stresses in Braces, it will be seen that—

"The Flange-Area ($A_1 + A_2$) depends partly on the Direct "Thrust (T or N), and partly on the distortion (δ), and in- "creases with both",.. } (28).

"The Brace-Stresses depend partly on the Direct Thrust "(T or N), and partly on the mutual obliquity (ϕ) of the "tangents to the Equilibrium Curve and Neutral Curve, "and increase with both",.................................. } (29).

Now in general it will be found that—

"The Direct Thrusts (T or N) increase *at all points* with "increase of the Load, and are therefore greatest when the "Span is fully loaded",.. } (30).

"The Equilibrium-Curves which depart most from the "Equilibrium-Curve for full loading lie nearly at equal dis- "tances above and below the latter",......................... } (31).

It is therefore advantageous to make the "Neutral Curve" of the Rib follow the Equilibrium-Curve for Full Load as nearly as possible, so that the Bending Action may be very small when the Rib is fully loaded, and the Direct Thrusts (T or N) therefore everywhere at their greatest values.

It will be found also that,—

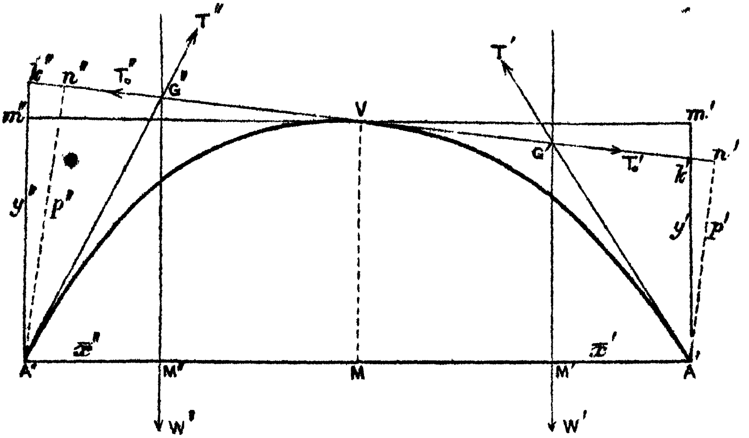
> " the greatest distortion (δ), and greatest obliquity (ϕ), are
> " produced by different conditions of Loading at each point,
> " but always by a very unsymmetric Load, varying,—
> " from ⅓-span loaded, ⅔-span unloaded, to ⅔-span loaded,
> " ⅓-span unloaded,
> " the Load being in each case placed in the most unsymmetric
> " possible position, *viz*., originating from one springing."

It is not possible to say *à priori* what distributions of Load produce maximum distortion or maximum obliquity at each point, but by actually drawing a good many Equilibrium-Curves, the following cases have been thought sufficient to work out in detail, as giving in some part or other

" Large Thrust (N or T) combined with large distortion (δ),"
viz., in case of left Semi-Arch, as in Table below.

CASE.	LOAD-SYSTEM.	Colour of Equilibrium-Curve in Diagram E.	EFFECT.
Case of Left Semi-Arch. [Neutral Curve a chain-dotted line].	Full Live Load,	Clear Black,	Largest values of N, T. Small distortion.
	Live Load on right ⅔-span,	Clear Red,	Large values of N, T. Great distortion below neutral curve.
	Live Load on left ⅓-span,	Upper Clear Blue,	Medium values of N, T. Great distortion above neutral curve.
	Live Load on right ⅓-span,	Lower Clear Blue,	Medium values of N, T. Great distortion below neutral curve.
	Live Load on left ⅓-span,	Clear Violet	Small values of N, T. Great distortion above neutral curve.

10. Formulæ for



Let W' = Total (vertical) Load on right half-arch VA'.

W'' = Total (vertical) Load on left half-arch VA''.

$G'M'$ is a vertical through centre of gravity of W'.

$G''M''$ is a vertical through centre of gravity of W''.

$\left.\begin{array}{l}\bar{x}' = A'M' \\ \bar{x}'' = A''M''\end{array}\right\}$ the abscissæ of centres of gravity of W', W'' measured from A', A'', respectively.

$k'k''$ is the tangent at the crown V.

$A'k' = A''k''$ are verticals through $A'A''$, to meet the tangent at crown; $A'k' = y'$, $A''k'' = y''$.

$A'n'$, $A''n''$ are the perpendiculars through A', A'' on the tangent at crown; $A'n' = p'$, $A''n'' = p''$.

$Vm = k$, (the Rise of the Arch).

By the property of the Equilibrium-Curve, the Thrust (T_0', T_0'') of either half-arch on the other is in direction Vk', Vk'', and the two are equal and opposite. Hence if the Resultants of the Loads W', W'' on either half-arch meet Vk', Vk'' in G', G'', respectively, then $A'G'$, $A''G''$ are the directions of the Thrusts (T', T'') at the springings.

Hence the half-arch VA' is balanced under the three Forces T_1

W′, T′ meeting at G′; and the half-arch VA″ is balanced under the three Forces T_0'', W″, T″ meeting at G″.

Hence taking Moments of these balanced systems round A′, A″, respectively,

$$T_0' \cdot p' = W' \cdot \bar{x}'; \quad T_0'' \cdot p'' = W'' \cdot \bar{x}, \dots\dots\dots (32).$$

Now the Horizontal Thrust (H) at V is the horizontal resolved part of T_0' or T_0'',

Hence, $$H = T_0' \cdot \cos m'Vk' = T_0'' \cdot \cos m''Vk'', \dots\dots (33).$$

But $\cos m'Vk' = \cos n'A'k' = \frac{p'}{y'}$; $\cos m''Vk'' = \cos n''A''k'' = \frac{p''}{y''}$.

$$\therefore H = T_0' \cdot \frac{p'}{y'} = T_0'' \cdot \frac{p''}{y''}, \dots\dots\dots\dots (34).$$

Substituting into (32), $H \cdot y' = W' \cdot \bar{x}'$, $H \cdot y'' = W'' \cdot \bar{x}''$, (35).

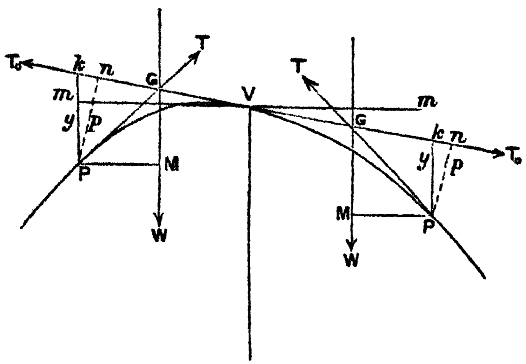
Adding these, $H \cdot (y' + y'') = W' \cdot \bar{x} + W'' \cdot \bar{x}''$.

But $y' + y'' = 2k$, $\therefore H = \frac{W' \cdot \bar{x}' + W'' \cdot \bar{x}''}{2k}$, ...(36).

And from (35), $y' = \frac{W' \cdot \bar{x}'}{H}$, $y'' = \frac{W'' \cdot \bar{x}''}{H}$, ...(37).

These are the formulæ required for calculating H, y', y''.

Again, to find the vertical depression (y) of any point P on the Equilibrium-Curve below the tangent at crown V, precisely similar reasoning applies.



Let W = Total Load between vertex (V) and any point P whether to right or left of crown.

GM be a vertical through centre of gravity of Load W.

Then $\bar{x}$ = PM = horizontal abscissa of centre of gravity of W from foot of arc VP.

kk is the tangent at crown, $Pk = y$ (the quantity sought).

Pk is a vertical through P (the foot of arc VP) to meet the tangent kk.

Pn is $\perp^r$ to the tangent kk.

Then, as before, the Thrust of either half arch on the other is a pair of equal opposite forces (T_o, T_o) in the line kk. And if the direction of the Resultant Load (W) meet this force T_o, (*i.e.*, the line kk) in the point G, then GP is the line of Thrust (T) at foot P of the arc VP, and the arc VP is balanced under the Forces T_o, W, T.

Taking moments of these balanced Forces about P,

$$T_o \,.\, p = W \,.\, \bar{x}, \qquad (38).$$

And it may be shown as before that,

$$H = T_o \,.\, \cos mVk = T_o \,.\, \cos nPk = T_o \,.\, \frac{p}{y} \qquad (39).$$

whence

$$H \,.\, y = T_o \,.\, p = W \,.\, \bar{x}, \qquad (40).$$

and, finally $y = \frac{W \,.\, \bar{x}}{H}$, the result required for calculating y,..(41).

Error in approximate Formula (19) for Flange-Areas.

11. It has been shown (Art. 4) that the *accurate* expression for the Total Area is

$$A = \frac{N}{s_c} + \frac{M \,.\, \bar{y}}{s_c \,.\, y_r^2}, \text{ (Eq. 16, Art. 4),}$$

$$= \frac{N}{s_c} + \frac{T\delta \,.\, \bar{y}}{s_c \,.\, y_r^2}$$

also that the approximate value is

$$A = \frac{T}{s_c} + \frac{T \,.\, \delta}{s_c \,.\, y'}, \text{ (Eq. 19, Art. 4),}$$

of which the first member $\left(\frac{N}{s_c} \text{ or } \frac{T}{s_c}\right)$ is in either case the value of the area (A_1) required to resist the Direct Thrust (N) alone; and since N, T are very nearly equal, these two values are very nearly equal, and the slight error in value of A_1 produced by using the value $T \div s_c$ instead of $N \div s_c$ (already explained to produce an error on safe side) is negligible.

The remaining portion of either expression is the value of the area (A_2) required to resist bending, *viz.*,

$$A_2 = \frac{T\delta}{s_c} \cdot \frac{\bar{y}}{y_r^2} = A_1 \frac{\delta \cdot \bar{y}}{y_r^2}, \textit{ accurately, } \ldots\ldots\ldots\ldots (42).$$

$$= \frac{T \cdot \delta}{s_c \cdot y'} = A_1 \frac{\delta}{y'}, \textit{ approximately, } \ldots\ldots\ldots\ldots (43).$$

Hence,

$$\text{Error in value of } A_2 = A_1 \frac{\delta}{y'} - A_1 \frac{\delta \cdot \bar{y}}{y_r^2}$$

$$= \left(1 - \frac{y' \cdot \bar{y}}{y_r^2}\right) \cdot A_1 \cdot \frac{\delta}{y'}$$

$$= \left(1 - \frac{y' \cdot \bar{y}}{y_r^2}\right) \times \text{approx. value of } A_2, (44).$$

CHAPTER III.—APPLICATION TO INDUS BRIDGE, OF THEORY OF CHAPTER II.

STEP. I.—The first Step is to *calculate the Loads actually applied* at the 20 points of suspension to the Actual Rib. This is shown on Calculation-Sheet A.

The Loads originally proposed (Col. 6) by the Designer having been found (by a preliminary calculation) to be too heavy, this Sheet shows a *modification* of them. An unnecessary amount of ballast having been provided in the original Design, it was decided to remove ·6 ton per foot run.

The amount of *ballast removed* from each point of suspension is calculated at ·6 ton × half width of two adjacent bays.

Col. 1 shows the *number* of each suspension-point reckoning from the crown (taken as zero) outwards.

Col. 2 shows the distance or abscissa (x'' or x''' in notation) of each suspension-point from the springing, taken by scale from the Diagram.

Col. 3 shows the width of bay between each pair of adjacent suspension-points, found by taking the difference of their abscissæ.

Col. 4 shows the half-width of sum of two adjacent bays, being found by taking the half sum of each adjacent pair of results in Col. 3.

Col. 5 shows the amount of *ballast removed* at each suspension-point, found (as above explained) by multiplying the Results in Col. 4 by ·6.

Col. 6 shows the Dead Loads at each point of suspension *as originally designed:* the data of this column were furnished by the Designer.

Col. 7 shows the ACTUAL DEAD LOAD applied at each suspension-point, found as the difference of results in Cols. 5, 6.

Col. 8 shows the FULL LIVE LOAD applied at each suspension-point found by multiplying the half-width of two adjacent bays (Col. 4) by ·8, thus making the Full Live Load ·8 ton per foot run.

Col. 9 shows the TOTAL LOAD applied at each suspension-point *when the Span is fully loaded,* found as sum of Cols. 7 and 8.

Col. 10 shows the LIVE LOAD applied at each suspension-point by a Partial Live Load *not covering the whole span,* taken at ·9 ton per foot run, found by multiplying the results of Col. 4 by ·9.

Col. 11 shows the TOTAL LOAD applied at each suspension-point by such Partial Live Load, being the sum of Cols. 7 and 10.

STEP II.—The next Step is the *calculation of the Moments* ($W' . \bar{x}'$ or $W'' . \bar{x}''$) under several conditions of the Live Load, and *of the abscissæ of centres of gravity* $\bar{x}'$ or $\bar{x}''$ of the Loads W′ or W″ *on the half arch.* This occupies Sheet B.

This has been done for six different arrangements of the live load *on semi-arch,*

Case I. Dead Load only.

Case II. Full Load.

Case III. Live Load at ·8 ton on ¼-span next centre + Dead Load on ½-span.

Case IV. Live Load at ·8 ton on ⅙-span next centre + Dead Load on ½-span.

Case V. Live Load at ·9 ton on complete ½-span + Dead Load on ½-span.

Case VI. Live Load at ·9 ton on ½-span next springing + Dead Load on ½-span.

The above arrangements refer to a semi-arch (or ½-span) only, so that by combining them in pairs, many arrangements of Load on the complete Arch result.

Col. 1 shows the number of each suspension-point reckoned from the crown outwards (taking the crown as zero).

Col. 2 shows the distances or abscissæ (x' or x'' in notation) of each suspension-point from the springing, taken by scale from the Diagram E.

Each of the columns marked I, II, III, IV, V, VI contains three sub-columns.

Sub-column 1, (headed Detail,) contains the Loads (w′ or w″ in notation), taken from Calculation-Sheet A applied at each suspension-point for the several Cases I to VI; the Total of these at foot of Table being of course the Total Load (W′ or W″) on the semi-arch for each case.

Sub-column 2, (headed Sums,) contains the sums of the Loads taken from the crown outwards; this column is used in plotting the Equilibrium-Curves.

Sub-column 3, (headed Moments,) contains the products of each Load (W′ or W″) by its distance (x' or x'') from nearest springing, *i. e.*, $w'x'$ or $w''x''$; the Totals of these being of course the Total Moments ($W' . \bar{x}'$ or $W'' . \bar{x}''$).

The last line but one contains the distances or abscissæ ($\bar{x}'$ or $\bar{x}''$) from springing of the centres of gravity of the several Total Loads of the several Cases I to VI, found by dividing the Total Moments ($W' . \bar{x}'$ or $W'' . \bar{x}''$) by the Total Loads W′ or W″.

The last line contains the values of the Horizontal Thrusts (H), supposing *both semi-arches, i. e.*, right and left of crown) loaded similarly to the several Cases I to VI, so that the whole Arch is symmetrically loaded, found by dividing the Total Moments by the rise of the Arch ($k = 200'$).

STEP III.—The next Step is the *finding the Horizontal Thrusts* (H) and *Elevations* (y', y'') *of the tangents at crown* above the springing *for the case of unsymmetric Load*, (*i.e.*, right and left semi-arches differently loaded).

This is done on Calculation-Sheet C by application of the formulæ

$$H = \frac{W'.\bar{x}' + W''.\bar{x}''}{2k}, \text{ Eq. (24) of Art. 5.}$$

$$y' = \frac{W'.\bar{x}'}{H}, \; y'' = \frac{W''.\bar{x}''}{H}, \text{ Eq. (25) of Art. 5,}$$

the values of $W'.\bar{x}'$, $W''.\bar{x}''$ being taken from Sheet B.

As already explained (Art. 9), it has been found (by previous trials) sufficient to work out a few cases only of unsymmetric load; the following statement shows how the values of $W'.\bar{x}$, $W''.\bar{x}''$ are taken from Sheet B; the live load originating at left springing in each case.

Live Load originating at left springing.	Reference to Sheet B.	
	Left Semi-Arch $W'.\bar{x}'$.	Right Semi-Arch $W'.\bar{x}'$.
Case i, Live Load on $\frac{3}{4}$-span,	Col. II, Sheet B	Col. III, Sheet B
Case ii, Live Load on $\frac{2}{3}$-span,	Col. II, Sheet B	Col. IV, Sheet B
Case iii, Live Load on $\frac{1}{2}$-span,	Col. V, Sheet B	Col. I, Sheet B
Case iv, Live Load on $\frac{1}{3}$-span,	Col. VI, Sheet B	Col I, Sheet B

Step IV.—The next Step is the *construction of as many Equilibrium-Curves* as may be thought necessary to enable, as far as possible, the maximum values of Shearing Force (F), and of Direct Stress due to the combined action of the Direct Thrust (N or T) and of the Bending action to be found at a good many points of the curve, under varied conditions of Load.

This has been done in the Diagram-Sheet marked E, by the method of Graphic Construction explained in Art. 7, for the *case of the left semi-arch.* For the reasons explained at end of Art. 9, it has been thought necessary to exhibit only five Equilibrium-Curves, which are shown together with their constructive details in differently coloured lines, *viz.*:—

CASE.	LOAD-SYSTEM.	Colour of Equilibrium-Curve in Diagram E.	EFFECT.
Case of Left Semi-arch. [Neutral Curve a chain-dotted line].	Full Live Load,	Clear Black,	Largest values of N, T. Small distortion.
	Live Load on right $\frac{2}{3}$-span,	Clear Red,	Large values of N, T. Great distortion below neutral curve.
	Live Load on left $\frac{1}{2}$-span,	Upper Clear Blue,	Medium values of N, T. Great distortion above neutral curve.
	Live Load on right $\frac{1}{2}$-span,	Lower Clear Blue,	Medium values of N, T. Great distortion below neutral curve.
	Live Load on left $\frac{1}{3}$-span,	Clear Violet,	Small values of N, T. Great distortion above neutral curve.

These five cases have been selected, having been found (by a preliminary trial) to give at some point or other,

"Large Thrust (N or T) combined with large distortion (δ)."

The lettering on this diagram is the same as on the small diagram with Art. 7, so that the detail of construction should be easy to follow.

1°. The *positions* of the crown V, springing A″, semi-span A″M, rise VM, and of the verticals through the centres of gravity of the several Loads, (or lines through the 20 points numbered 1 to 20,) have been taken from the Designer's sketch.

2°. The horizontal distances or abscissæ (A″*m* or $\bar{x}''$) of verticals (G*m*) through the several centres of gravity of the several Load-systems (W″) on the Semi-arch are taken from Calculation-Sheet B, and the several verticals *m*G drawn.

3°. The elevations (A″*k*, *i.e.*, y' or y'') of the tangents (V*k*) at the crown under the several Load-systems are taken from Calculation-Sheet C; the intersections of the tangents V*k* so drawn with the verticals *m*G through the centres of gravity of the several Load-systems are marked G, with a circle drawn round the intersection (so as to avoid confusion of numerous radiating lines meeting at G).

4°. The several Load Lines (T, 1, 2, 3,......... 20) are vertical lines drawn at the several horizontal distances from the several verticals *m*G, representing on a scale of 100 tons to an inch the values of the Horizontal Thrusts (H) for the several Load-systems taken—

for case of symmetric Load from Sheet B,
for case of unsymmetric Load from Sheet C.

5°. The several lengths on the Load Lines showing the Loads between the crown and the points 1, 2, 3, ... 20 of the Rib, *viz*., T, 1; T, 2; T, 3; .... T, 20; are taken from the sub-columns headed "Sums" in Calculation-Sheet B for the several Load-systems.

6°. The rest of the construction of the five Equilibrium-Curves will be readily followed from Art. 9.

STEP. V.—It has been already explained in Art. 9 that it is advantageous to make the "neutral curve" of the Rib *follow the Equilibrium-Curve for full Load* as nearly as possible. Constructive convenience however requires that the "neutral curve" should consist of *only a few circular arcs*, with common tangents at their points of union.

A "neutral curve" consisting of *only two circular arcs* in each semi-span *closely following* the Equilibrium-Curve for Full Load (clear black line in Diagram E), has been found by trial (chain-dotted black line in Diagram E) with two radii of 369 and 618 feet, respectively; the pair of circular arcs of radii of 369 feet meet at the crown with a horizontal tangent, so that their centre is on the vertical (VM) through the crown; the radius 369 feet is used from the crown to the 8th point, and the radius 618 feet from the 8th point to the springing; and there is a common tangent at the 8th point.

[*N.B.*—It is possible, and even likely, that when the constructive details are worked out with this "neutral curve" for the Rib, the centres of gravity of the several *actual* Loads may be found not to fall on the *assumed verticals* marked 1, 2, 3,............20; or again the *actual* Loads themselves may be found not to agree with the Loads *assumed* in Sheet A. Should either of these possible discrepancies be *considerable*, the Equilibrium-Curves will of course be considerably affected, and it will be necessary to go through the whole process again. In fact the present Results can only be regarded as preliminary].

STEP. VI.—*To find the Direct Thrusts* (T) in the bay between each pair of points. This is at once done by scaling (with a scale of 100 tons to an inch) from the centre of the several circles marked G, to the several points marked T, 1, 2, 3,.........20 on the several Load Lines. The Results are shown in Calculation-Sheet D in the sub-columns T.

STEP. VII.—*To find the distortions or departures* (δ) of the Equilibrium-Curves from the "neutral curve" of the Rib (chain-dotted black line).

This is at once done by measuring (with the scale of 40 feet to an inch) from the several points 1, 2, 3,.........20 on the "neutral curve" the perpendicular lengths (δ) to the corresponding *sides* of the "Funicular Polygon" for each Load-system. The Results are shown in Calculation-Sheet D in the sub-columns δ.

STEP. VIII.—*To find the Flange-Areas.*—(*See* Art. 4).

For the reasons given in Art 3, *viz.*, the small obliquity between the "neutral curve" of the Rib and each Equilibrium-Curve *at corresponding points*, the values of the Direct Thrust (N) perpendicular to the normal cross-sections of the Rib, and of the tangential Thrust (T) in the Equilibrium-Curves are so nearly equal, that it has not been considered worth while undertaking the labour of calculating the accurate values of the former; and the (already found) values of T are taken for N.

The value of the quantity,—

$$\left.\begin{array}{l}\text{Maximum mean crushing stress-intensity}\\ \text{admissible (denoted by } s_c \text{ in the notation),}\end{array}\right\} = 6\cdot5 \textit{ tons per sq. in.}$$

for the material (steel) of the Rib; the Flange-areas ($A = A_1 + A_2$) are now easily found by the approximate formula (19) of Art 4, the half depth (y') of the Rib being taken as 11 feet.

The Area (A_1) required to meet the Direct Thrust (T) alone is at once found by dividing the Results in the sub-columns T o Calculation-Sheet D by 6·5.

The additional Area (A_2) required to meet the bending action i at once found by multiplying the (already found) values of A_1 b

the quantity $\frac{\delta}{11}$, since $y' = \frac{1}{2} \times 22' = 11'$.

The Total Area (A) required is now at once found, as the sun of the partial Areas ($A_1 + A_2$).

The Results are exhibited for the several Load-systems in th sub-columns marked A_1, A_2, A of Calculation-Sheet D.

[It has not been thought worth while to work out these Results *for every Bay* but only for a sufficient number of Bays to exhibit the maxima with tolerabl certainty].

The maximum resulting Flange-Areas (A) for each Bay are clearly exhibited by being printed in black letter type. Thus it will b seen that the

Max. Flange-Area required at crown = 141 *sq. in.*
" " " at springing = 213 *sq. in.*
Max. maximorum Flange-Area required = 208 *sq. in.*

STEP IX.—*To find the Shearing Stresses* (F) across the Rib.

These being the resolved parts parallel to the normal cross-sections of the Rib of the tangential Thrusts (T) in the Equilibrium-Curves, (*see* Art. 3,) are at once found from the Diagram E, thus:—

1°. The radii of the circular arcs composing the "Neutral curve" of the Rib are drawn through all the points 1, 2, 3,......20, of the "neutral curve"; these give the *directions* of its normal sections; perpendiculars are drawn to each of these radii at these points 1, 2, 3,......20 of the "neutral curve", which are therefore the tangents to the "neutral curve" at those points.

2°. Parallels to these tangents may now be drawn (with the parallel ruler) through the several points G on the Diagram E, and the perpendicular distance of the further end of the radiator from G which represents the Thrust (T) in the Equilibrium-Curve for each point of the "Neutral Curve" measured on the scale of 100 tons to an inch) to the respective tangents. These quantities are of course the resolved parts required. As this measurement can be done with a plotting scale run along the edge of the parallel ruler, it can be pretty rapidly done.

The Results (values of F) are to be considered of opposite sign according as the perpendicular is measured upwards or downwards.

The Results are shown in the sub-columns marked F of the Calculation-Sheet F for the several Load-systems; it will be seen that the Shearing Force (F) varies from + 90 to − 92 as the maximum range, and from + 81 to − 82 at the crown, and is on the whole greatest near both crown and springing, and decreases thence towards the 8th point.

STEP X.—*To find the Stresses* R *in the Braces.*—These are at once found by the formula R = F . cosec *i*, (Art. 2,) which gives the *magnitude* of R.

From the elevation of the Rib, it appears that cosec *i* = 1·5 nearly. The *character* (as to compression or tension) depends *on the sign of* F, just as in an ordinary horizontal Girder.

A few only of the values of these Stresses have been taken out in the Calculation-Sheet F, in the sub-column R; enough to show the maxima and minima. It will be seen that the

Braces at the crown are liable to about 123 tons of *alternate* tension and compression.

Braces near the springing are liable to about 138 tons of *alternate* tension and compression.

Braces at the 8th point are liable to about 48 tons of *alternate* tension and compression.

And in general it may be inferred from the fact of the "Neutral Curve" of the Rib lying *nearly half way* between the upper and lower Equilibrium-Curves of maximum distortion (*see* Diagram E) that the pair of Braces (intended for Tension and Compression) at any part of the Rib will be liable to *about equal amounts* of Tension and Compression.

[*N.B.*—There is a small additional Stress to be borne by the braces due to the cause explained in the N.B. at end of Art. 2, *q.v.*, not thought worth while determining].

Step XI.—Error in approximate Formula (19) for Flange-Areas.

Applying the formula (44) of Art. 11 to the case of the Sukkur Bridge, for which it appears from the cross-section and Calculation-Sheet G, that $y' = 11' = 132''$, $y_r = 134''\cdot5$, $\bar{y} = 134''\cdot234$.

$$\therefore \text{ Error in value of } A_2 = \left(1 - \frac{132'' \times 134''\cdot234}{134''\cdot5 \times 134''\cdot5}\right) \times \text{approx. value of } A_2$$

$$= (1 - \cdot98) \times \text{approx. value of } A_2$$

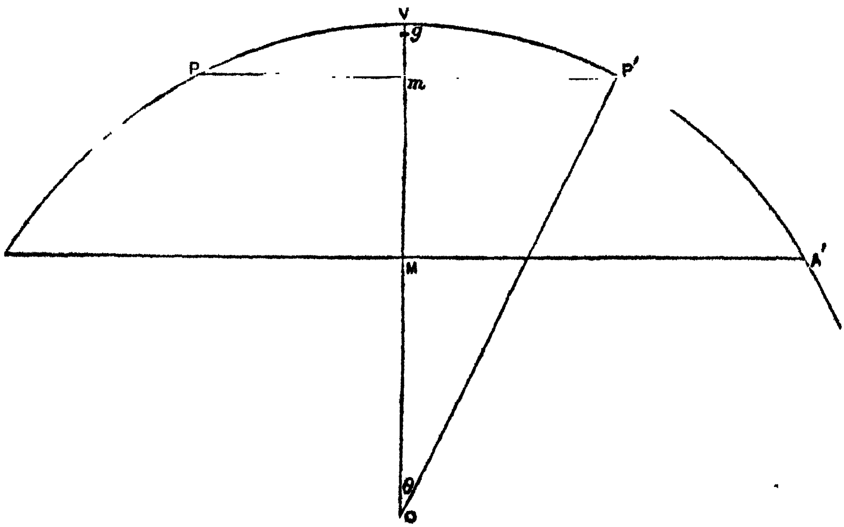
$$= \cdot02 \times \text{approx. value of } A_2.$$

Thus the approximate formula causes an error of about two per cent. *in excess* (because the approximate is greater than the accurate value) in value of A_2, *i.e.*, of the portion required to resist bending.

Now as the maximum value of A_2 is about equal to, and nowhere exceeds A_1, (see Calculation-Sheet D,) *i.e.*, is about equal to, and nowhere exceeds ½ A or ⅓ of the Total Area, it follows that—

"Maximum Error in Total Area at any part of the Rib } does not exceed 1 per cent., and is on side of safety."

CHAPTER IV.—EFFECT OF WIND.



1. $2s$ = length of any arc PVP′ symmetric about vertex, (PV = s = VP′).

2ξ = length of chord PP′ symmetric about vertex (Pm = ξ = mP′).

k = mV the rise of arc PVP′.

θ = angle $V\hat{O}P' = V\hat{O}P$.

R = Radius of arc.

$\bar{x}$ = mg, where g is centre of gravity of arc PP′.

b = average breadth of arc exposed to wind, *in feet.*

f = wind-pressure *in tons per sq. ft.* $= \frac{40}{2240} = \frac{1}{56} =$ ·017857 *tons per sq. ft.*

P = Total Wind-Pressure on Rib PVP′ (*i. e.*, on arc $2s$) *in tons.*

M = Moment of ditto about line PmP′ *in ft. tons, i. e.*, the "Bending Moment".

Then $$P = fb \,.\, 2s, \qquad (1).$$
$$M = P \,.\, \bar{x}, \qquad (2).$$

Also Q = Total Vertical Pressure on sum of areas at feet (P, P′) of arc PVP′ = Total Vertical Tension on sum of areas at feet (P, P′) of arc PVP′ } due to Wind.

$\bar{y}$ = distance between centres of roadways = 66′.

Then $$Q = P \,.\, \frac{\bar{x}}{\bar{y}}, \qquad (3).$$

Also; $\frac{Q}{2}$ = Total Vertical Pressure (or Tension) due to wind at either foot of arc PVP′ on one side of crown, } (4).

$\frac{1}{3} \,.\, \frac{Q}{2}$ = Total Vertical Pressure (or Tension) *on inner Rib at either foot* P, P′ of arc PVP′, ... } (5).

$\frac{2}{3} \,.\, \frac{Q}{2}$ = Total Vertical Pressure (or Tension) *on outer Rib at either foot* P, P′ of arc PVP′, ... } (6).

The above Pressures or Tensions are all vertical, and estimated over the *horizontal* plane areas of the Rib at P or P′.

Those *vertical* Pressures (or Tensions) produce

Normal $\left\{\begin{array}{l}\text{Pressure}\\ \text{or Tension}\end{array}\right\}$ over a normal section = Vertical Pressure × sin θ, ... (7).

± Shearing Force parallel to normal section = Vertical Pressure × cos θ, ... (8).

Hence—

Normal Pressure (or Tension) over a normal section,... of inner Rib $= \frac{1}{3} \cdot \frac{Q}{2} \sin\theta$, ...(9).

of outer Rib $= \frac{2}{3} \cdot \frac{Q}{2} \sin\theta$,......(10).

Shearing Force (±) parallel to normal section, ... of inner Rib $= \frac{1}{3} \cdot \frac{Q}{2} \cos\theta$,......(11).

of outer Rib $= \frac{2}{3} \cdot \frac{Q}{2} \cos\theta$,......(12).

It remains only to calculate ($\bar{x}$) the distance of centre of gravity of arc PVP′ from P*m*P′. Now on account of the roughness of the approximation (in calculation of the Total Wind-Pressure P), it will suffice to calculate $\bar{x}$ as if the arc VP were for every position of P part of a circle with centre on the vertical VM through the vertex.

And in this case it is known that $Og = R\frac{\sin\theta}{\theta} = R \times \frac{R\sin\theta}{R\theta} = R \times \frac{\xi}{s}$.

Hence $\qquad Vg = R - Og = R \cdot \left(1 - \frac{\xi}{s}\right)$

And $\qquad \bar{x} = mg = mV - Vg = k - R \cdot \left(1 - \frac{\xi}{s}\right)$, ...(13).

APPLICATION TO INDUS BRIDGE.

2. Calculation-Sheet H shows the Results of application of the formulæ for effect of Wind-Pressure to the case of the Indus Bridge.

Data furnished by Designer—

Wind-pressure intensity, f = 40 lbs. per sq. ft. = ·017857 tons per sq. ft.

Nett average breadth of Rib exposed to wind, $b = 11'$.

Distance between centres of roadways, $\bar{y} = 66'$.

Col. 1° shows the number of joint reckoned from crown (taken as zero) outwards.

Col. 2° shows the radius of the "neutral curve" of Rib at each point of Col. 1°, (taken from Sheet E).

Col. 3° shows the distance (ξ) of each point in Col. 1° from a vertical line through the crown, (taken from Sheet B,) which is the same as the semi-chord required in formula (13).

Col. 4° shows the semi-arc (s) measured from crown down to each point of Col. 1°, taken from Diagram E, allowing 22 feet for each complete Bay measured along the Neutral Curve.

Cols. 5°, 6° contain the Rise (k) and Slope (θ) of each semi-arc, taken by scale from the Diagram E.

Col. 10° contains the vertical distance ($\bar{x}$) of centre of gravity of each complete arc from a horizontal line through its two feet, calculated by formula (13) for application in formulæ (2), (3).

Col. 11° contains the Total Wind-Pressure upon each complete arc, *i.e.*, between crown and each numbered joint.

Cols. 13° to 19° contain the effects of the Wind-Pressure, as follows:—

Col. 13° contains the Total Increase of Vertical Pressure ($\frac{1}{2}$ Q) upon horizontal planes through each numbered joint, found by Eq. (3), (4).

Cols. 14°, 15° contain the portions of above falling on the inner and outer Ribs respectively.

Cols. 16°, 17°, 18°, 19° contain the effects of the above *upon the normal cross-sections* at the numbered joints of the inner and outer Ribs, respectively, found by formulæ (9), (10), (11), (12).

It will be seen that—as might be expected—

"The maximum Wind-effect takes place at the springing", and amounts to an

"Increase of Vertical Pressure of 48 tons on inner Rib,
96 tons on outer Rib";

the effect of which *on the normal cross-sections* near the springing is—

"Increase of Direct Thrust of 37 tons on inner Rib,
74 tons on outer Rib".

"Increase of Shearing-Stress of 30½ tons on inner Rib,
61 tons on outer Rib".

And supposing the sum of Flange-Areas of one complete Roadway (or of two Ribs) to be about 270 *sq. in.* as shown to be necessary in Calculation-Sheet D, or about 135 *sq. in.* for each Rib, this maximum Increase of Direct Thrust of 37 and 74 tons upon the inner and outer Ribs near the springing gives a,—

Max. Increase of pressure-intensity of ·27 *tons per sq. in.* in inner Rib, ·55 *tons per sq. in.* in outer Rib.

[It has not been thought necessary to work out the Results for every one of the numbered Joints; the Results for the six Joints Nos. 4, 8, 11, 14, 17, 21 show all that is required].

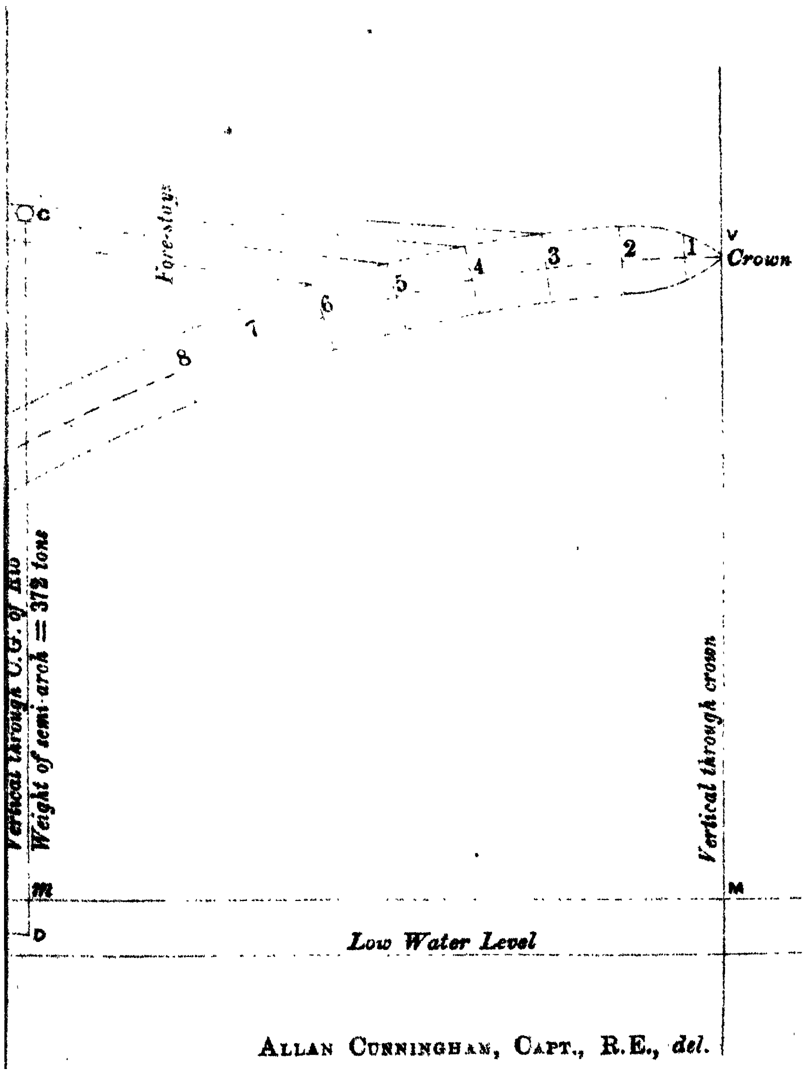
CHAPTER V.—STRESSES IN STAYS DURING ERECTION.

1. From the mode of erection, it is clear that the greatest Stresses occur in the Stays—whether Fore-stays, or Back-stays—when the Semi-arches are complete, and are on the point of being united.

In the Sketch-Diagram for finding the Stresses in Stays during erection, the position and size of Trestle, and the position of Back-stay and of its anchoring have been taken from the Designer's sketch. At the moment of completion, the Rib would be retained by four Fore-stays fastened to the points in the top Boom marked 3, 4, 5, 6, and the Tensions of these would be equalized by hydraulic presses.

The direction of the Resultant of the Tensions in the four fore-stays is therefore easily found, (by bisecting the angles between any two pairs, and also the angle between these two bisectors,) and is *shown by a chain-dotted line* OG in Diagram.

The distance of a vertical G*m* through the centre of gravity of the complete (unloaded) semi-arch from the springing A having been found to be A*m* = 166′·9, (*see* Calculation-Sheet K,) the vertical G*m* is drawn, and from G (the point where it cuts OG) the Load line GD is set off to represent the Load of semi-arch, *viz.*, 372 tons, and GA is joined, and DE drawn parallel to GO to meet GA in E.



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Then DE = 270 tons, shows the Total Tension in the four fore-stays.

GE = 448 tons, shows the Thrust at the springing.

Hence Tension of each fore-stay = $\frac{1}{4} \times 270 = 67\frac{1}{2}$ tons.

Next to find the Tension of the Back-stays and Pressure on Trestle, it is clear from the mode of *free suspension at the head* C of the Trestle, the Suspension-Link CO is free to take any position, *i.e.*, to *change in direction* until the Stresses in the Fore-stays, Back-stays and Suspension-Link itself (which all meet in O) are balanced, and it is clear that unless *prevented from moving* by adjusting the Back-stay from time to time, it will certainly do so.

Now any such motion of the Suspension-Link (CO) will be—unless confined within very narrow limits—*highly dangerous to the safety of the trestle.* The direction of the line CO is in fact the *direction of Resultant Pressure* on the Trestle: now when this line is vertical, the Resultant Pressure on the Trestle will be *wholly downward vertical Pressure,* and this is the only favourable condition.

As the line CO inclines either way, there will be partial Transverse Strain on the Trestle; this will not be dangerous so long as the direction of CO falls within the volume of the Trestle: when the line CO is directed towards either edge of the Trestle the *whole Pressure will be on that edge,* and if the line CO deviates outside the Trestle, the Trestle will be thrown into state of a Cantilever, and there will be a tendency to *snap it across,* or to *lift it from its bed.*

It is therefore highly desirable that the direction of the line CO be maintained *as nearly as possible vertical,* and this can be done by pulling the back-stay O*f* towards the ground, so as to deflect it into a Curve (as shown in Designer's sketch), and thereby increase or decrease the Tension in it at will.

Provided this vertical position be maintained, the Total Tension in the Back-stays and Pressure on the Trestle are easily found; thus—

On OG take O*e* to represent 270 tons, the Total Tension of the

Fore-stays (already found), and draw eK parallel to the Back-stay Of to meet the now vertical line CO in K.

Then OK = 184 tons, the Total Pressure on Trestle, (when the Back-stay is straight).

eK = 310 tons, the Total Tension of Back-stays, *when quite straight.*

Supposing that in the endeavour to keep the line CO vertical, it is found necessary to strain the Back-stay Ofz into the curved form $Of'z$, the actual Tension of the Back-stay and Pressure on Trestle are easily found by a similar construction: taking Oe (as before) = 270 tons, eK' is drawn parallel to Of', to meet the vertical line CO in K'. Then as before

OK' = 225 tons, the Total Pressure on Trestle.

eK' = 335 tons, the Total Tension of Back-stay Of' (near its attachment to the Trestle).

The horizontal Thrust in the Rib, and horizontal Tension of Fore-stays and Back-stays is in each case the same, *viz.*, 268 tons.

EFFECT OF WIND DURING ERECTION.

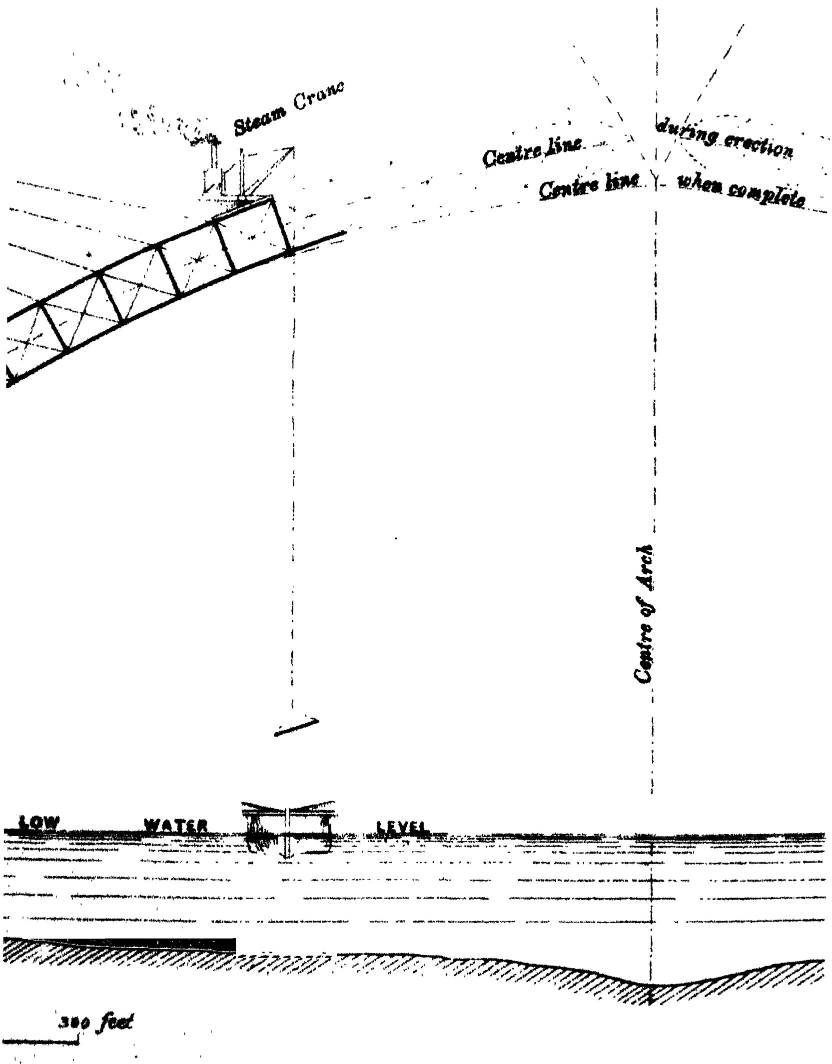
2. It remains to investigate the effect of Wind during erection. Consider first the effect of a Wind perpendicular to the face of the Rib. This will produce a *much greater straining effect on the Rib itself*, before the two semi-arches are united at the crown, than after completion of the bridge; because

(1) before union at crown such a Wind throws the Rib into state of a Cantilever fixed at A, of virtual length AV = 420 feet.

(2) after completion such a Wind throws the complete Rib into state of a Cantilever fixed at both springings of virtual length VM = 200 feet.

But inasmuch as before union at crown, the Rib has only its weight to sustain *without any platform*, such enhanced Wind effect is of no importance, and need not be further investigated.

Consider next the effect of a wind blowing across the river: now


Steam Crane
Centre line
during erection
Centre line
when complete
Centre of Arch
LOW
WATER
LEVEL
300 feet

inasmuch as the Trestle must necessarily be made capable of standing the effect of such a cross-wind *of itself, i.e.*, before it receives the aid of the Tensions of the Fore- and Back-Stays, the effect on the Trestle need not be further considered.

Consider next the effect of a Wind blowing across the River *upon the under side* of the Rib: this would virtually lighten the weight of the Rib, and so relieve part of the Tension of the Forestays, and therefore also part of the Tension of the Back-stays.

Consider next the effect of a Wind blowing across the River *upon the upper side* of the Rib: the pair of Ribs expose an area to the Wind whose vertical projection may be roughly estimated at 200′ (height of Rib) × 15′, so that the Wind (taken at 40 lbs. per sq. ft. of a vertical surface) will produce a

$$\left.\begin{array}{c}\text{Total Horizontal Pressure}\\ \text{on convex side of Rib}\end{array}\right\} = \frac{40}{2240} \times 200' \times 15' = 54 \textit{ tons, nearly.}$$

Half of this will take effect at head of Trestle and half at Springing of Rib, *viz.*,

$$\left.\begin{array}{l}\text{Increase of horizontal Tension at O} = 27 \text{ tons,}\\ \text{Decrease of horizontal Pressure at A} = 27 \text{ tons.}\end{array}\right\}$$

As this is an increase of about $\frac{1}{10}$ in the Horizontal Tension, the other Stresses will be *similarly increased, viz.*, by about $\frac{1}{10}$ of their normal amounts.

CHAPTER VI.—CALCULATION SHEETS.

CALCULATION OF APPLIED LOADS.

[*See* Step I, Chap. III.]

A.

1	2	3	4	5	6	7	8	9	10	11
	ABSCISSÆ.*	WIDTHS.		DETAIL OF LOADS.						
Number.	From springing. x' or x''.	Width of intervening Bay.	Half width of two adjacent Bays.	Ballast removed.† at ·6 tons.	Original Dead Load.‡	ACTUAL DEAD LOAD.	Full Live Load‡ at ·8 tons.	DEAD LOAD + FULL LIVE LOAD. at ·8 tons.	Partial Live Load. at ·9 tons.	DEAD LOAD + PARTIAL LIVE LOAD at ·9 tons.
0	370·0		..	..	..	..	..	..	..	..
		10·0								
1	360·0		14·3	8·58	44·3	35·7	11·44	47·1	12·87	48·6
		18·5								
2	341·5		20·3	12·18	49·6	37·4	16·24	53·6	18·27	55·7
		22·0								
3	319·5		22·1	13·26	51·8	38·5	17·68	56·2	19·89	58·4
		22·1								
4	297·4		22·0	13·20	51·7	38·5	17·60	56·1	19·80	58·3
		21·9								
5	275·5		21·6	12·96	51·5	38·5	17·28	55·8	19·44	57·9
		21·3								
6	254·2		21·4	12·84	51·2	38·4	17·12	55·5	19·26	57·7
		21·4								
7	232·8		21·2	12·72	50·9	38·2	16·96	55·2	19·08	57·3
		21·0								

8	211·8	20·4	20·7	12·42	50·8	38·4	16·56	55·0	18·63	57·0
9	191·4	20·2	20·3	12·18	50·6	38·4	16·24	54·6	18·27	56·7
10	171·2	19·4	19·8	11·88	50·3	38·4	15·84	54·2	17·82	56·2
11	151·8	18·8	19·1	11·46	49·7	38·2	15·28	53·5	17·19	55·4
12	133·0	18·8	18·8	11·28	49·0	37·7	15·04	52·7	16·92	54·6
13	114·2	17·6	18·2	10·92	48·2	37·3	14·56	51·9	16·38	53·7
14	96·6	17·4	17·5	10·50	47·6	37·1	14·00	51·1	15·75	52·9
15	79·2	16·2	16·8	10·08	50·0	39·9	13·44	53·3	15·12	55·0
16	63·0	16·0	16·1	9·66	51·0	41·3	12·88	54·2	14·49	55·8
17	47·0	14·6	15·3	9·18	52·0	42·8	12·24	55·0	13·77	56·6
18	32·4	14·2	14·4	8·64	56·1	47·5	11·52	59·0	12·96	60·5
19	18·2	11·2	12·7	7·62	47·1	39·5	10·16	49·7	11·43	50·9
20	7·0	7·0	9·1	5·46	17·7	12·2	7·28	19·5	8·19	20·4
21	Nil		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
TOTALS		370·0	361·7	217·02	971·1	753·9	289·36	1,043·2	325·53	1,079·6

* taken from Diagram E.
† by direction of Designer.
‡ furnished by Designer.

CALCULATION OF MOMENTS ($W'. \bar{x}'$, $W''. \bar{x}''$), AND OF
[*See* Step II,

Number.	ABSCISSÆ from Diagram E. From springing x' or x''	I. Dead Load on half-span. Detail W.	Sums.	Moments.	II. Full Load on half-span. Detail W.	Sums.	Moments.	III. Dead Load on half-span + Live Load (at ·8) on quarter-span next centre. Detail W.	Sums.	Moments.
0	..	..	..	..	..	..	..	..	..	..
1	360·0	35·7	35·7	12,852·00	47·1	47·1	16,956·00	47·1	47·1	16,956·00
2	341·5	37·4	73·1	12,772·10	53·6	100·7	18,304·40	53·6	100·7	18,304·40
3	319·5	38·5	111·6	12,300·75	56·2	156·9	17,955·90	56·2	156·9	17,955·90
4	297·4	38·5	150·1	11,449·90	56·1	213·0	16,684·14	56·1	213·0	16,684·14
5	275·5	38·5	188·6	10,606·75	55·8	268·8	15,372·90	55·8	268·8	15,372·90
6	254·2	38·4	227·0	9,761·28	55·5	324·3	14,108·10	55·5	324·3	14,108·10
7	232·8	38·2	265·2	8,892·96	55·2	379·5	12,850·56	55·2	379·5	12,850·56
8	211·8	38·4	303·6	8,133·12	55·0	434·5	11,649·00	55·0	434·5	11,649·00
9	191·4	38·4	342·0	7,349·76	54·6	489·1	10,450·44	54·6	489·1	10,450·44
10	171·2	38·4	380·4	6,574·08	54·2	543·3	9,279·04	54·2	543·3	9,279·04
11	151·8	38·2	418·6	5,798·76	53·5	596·8	8,121·30	38·2	581·5	5,798·76
12	133·0	37·7	456·3	5,014·10	52·7	649·5	7,009·10	37·7	619·2	5,014·10
13	114·2	37·3	493·6	4,259·66	51·9	701·4	5,926·98	37·3	656·5	4,259·66
14	96·6	37·1	530·7	3,583·86	51·1	752·5	4,935·26	37·1	693·6	3,583·86
15	79·2	39·9	570·6	3,160·08	53·3	805·8	4,221·36	39·9	733·5	3,160·08
16	63·0	41·3	611·9	2,601·90	54·2	860·0	3,414·60	41·3	774·8	2,601·90
17	47·0	42·8	654·7	2,011·60	55·0	915·0	2,585·00	42·8	817·6	2,011·60
18	32·4	47·5	702·2	1,539·00	59·0	974·0	1,911·60	47·5	865·1	1,539·00
19	18·2	39·5	741·7	718·90	49·7	1023·7	904·54	39·5	904·6	718·90
20	7·0	12·2	753·9	85·40	19·5	1043·2	136·50	12·2	916·8	85·40
21	Nil	Nil	..	Nil	Nil	..	Nil	Nil	..	Nil
TOTALS	..	753·9	..	129,465·96	1043·2	..	182,777·72	916·8	..	172,383·74
Abscissæ of centres of gravity from springing. $\bar{x}'$ or $\bar{x}''$				171·7			175·2			188·0
Horizontal Thrusts for Symmetric Loads.				647·3			913·9			861·9

Abscissæ of Centres of Gravity ($\bar{x}'$,
Chap. III.]

B.

IV. Dead Load on half-span + Live Load (at ·8) on sixth-span next centre.			V. Dead Load on half-span + Live Load (at ·9) on half-span.			VI. Dead Load on half-span + Live Load (at ·9) on third-span next springing.		
Detail W.	Sums.	Moments.	Detail W.	Sums.	Moments.	Detail W.	Sums.	Moments.
..	..	..	..	..	..	..	..	..
47·1	47·1	16,956·00	48·6	48·6	17,496·00	35·7	35·7	12,852·00
53·6	100·7	18,304·40	55·7	104·3	19,021·55	37·4	73·1	12,772·10
56·2	156·9	17,955·90	58·4	162·7	18,658·80	38·5	111·6	12,300·75
56·1	213·0	16,684·14	58·3	221·0	17,338·42	38·5	150·1	11,449·90
55·8	268·8	15,372·90	57·9	278·9	15,951·45	38·5	188·6	10,606·75
55·5	324·3	14,108·10	57·7	336·6	14,667·34	38·4	227·0	9,761·28
55·2	379·5	12,850·56	57·3	393·9	13,339·44	57·3	284·3	13,339·44
38·4	417·9	8,133·12	57·0	450·9	12,072·60	57·0	341·3	12,072·60
38·4	456·3	7,349·76	56·7	507·6	10,852·38	56·7	398·0	10,852·38
38·4	494·7	6,574·08	56·2	563·8	9,621·44	56·2	454·2	9,621·44
38·2	532·9	5,798·76	55·4	619·2	8,409·72	55·4	509·6	8,409·72
37·7	570·6	5,014·10	54·6	673·8	7,261·80	54·6	564·2	7,261·80
37·3	607·9	4,259·66	53·7	727·5	6,132·54	53·7	617·9	6,132·54
37·1	645·0	3,583·86	52·9	780·4	5,110·14	52·9	670·8	5,110·14
39·9	684·9	3,160·08	55·0	835·4	4,356·00	55·0	725·8	4,356·00
41·3	726·2	2,601·90	55·8	891·2	3,515·40	55·8	781·6	3,515·40
42·8	769·0	2,011·60	56·6	947·8	2,660·20	56·6	838·2	2,660·20
47·5	816·5	1,539·00	60·5	1,008·3	1,960·20	60·5	898·7	1,960·20
39·5	856·0	718·90	50·9	1,059·2	926·38	50·9	949·6	926·38
12·2	868·2	85·40	20·4	1,079·6	142·80	20·4	970·0	142·80
Nil	..	Nil	Nil	..	Nil	Nil	..	Nil
868·2	..	163,062·22	1,079·6	..	189,494·60	970·0	..	156,103·82
		187·8			175·5			160·9
		815·3			947·5			780·5

UNSYMMETRIC LOAD.

HORIZONTAL THRUSTS AND ELEVATIONS OF TANGENTS AT CROWN ABOVE SPRINGING.

[*See* Step III, Chap. III.] **C.**

---

i. *Live Load on* $\frac{3}{4}$*-span*, (at ·8 ton).

$$W''.\bar{x}'' = 182{,}777{\cdot}72$$
$$W'.\bar{x}' = 172{,}383{\cdot}74$$
$$\therefore\ 2kH = 355{,}161{\cdot}46, \text{ and } H = 887{\cdot}9037 \textit{ tons.}$$

$$y'' = \frac{182{,}777{\cdot}72}{887{\cdot}904} = 205'{\cdot}9$$
$$y' = \frac{172{,}383{\cdot}74}{887{\cdot}904} = 194'{\cdot}1$$

---

ii. *Live Load on* $\frac{2}{3}$*-span*, (at ·8 ton).

$$W''.\bar{x}'' = 182{,}777{\cdot}72$$
$$W'.\bar{x}' = 163{,}062{\cdot}22$$
$$\therefore\ 2kH = 345{,}839{\cdot}94, \text{ and } H = 864{\cdot}5998 \textit{ tons.}$$

$$y'' = \frac{182{,}777{\cdot}72}{864{\cdot}6} = 211'{\cdot}4$$
$$y' = \frac{163{,}062{\cdot}22}{864{\cdot}6} = 188'{\cdot}6$$

---

iii. *Live Load on* $\frac{1}{2}$*-span*, (at ·9 ton).

$$W''.\bar{x}'' = 189{,}494{\cdot}60$$
$$W'.\bar{x}' = 129{,}465{\cdot}96$$
$$\therefore\ 2kH = 318{,}960{\cdot}56, \text{ and } H = 797{\cdot}4014 \textit{ tons.}$$

$$y'' = \frac{189{,}494{\cdot}60}{797{\cdot}4} = 237'{\cdot}6$$
$$y' = \frac{129{,}465{\cdot}96}{797{\cdot}4} = 162'{\cdot}4$$

---

iv. *Live Load on* $\frac{1}{3}$*-span*, (at ·9 ton).

$$W''.\bar{x}'' = 156{,}103{\cdot}82$$
$$W'.\bar{x}' = 129{,}465{\cdot}96$$
$$\therefore\ 2kH = 285{,}569{\cdot}78, \text{ and } H = 713{\cdot}9245 \textit{ tons.}$$

$$y'' = \frac{156{,}103{\cdot}82}{713{\cdot}925} = 218'{\cdot}7$$
$$y' = \frac{129{,}465{\cdot}96}{713{\cdot}925} = 181'{\cdot}3$$

STRESSES

See Steps VI., VII., VIII., Chap. III., { A_1 = Cross-section of both Flanges to bear
A_2 = Additional ditto ditto to bear

Number of Bay.	Full Load.					Load on $\frac{5}{8}$-span from right.				
	T	A_1	δ	A_2	A	T	A_1	δ	A_2	A
0– 1 1– 2 2– 3 3– 4	914	141	...	...	**141**	867	133	...	...	133
4– 5 5– 6 6– 7 7– 8	939	145	$\frac{3}{4}$	10	155	897	138	$2\frac{1}{2}$	31	169
8– 9	1,012	156	...	...	156	973	150	6	82	232
9–10	1,037	160	$\frac{1}{2}$	7	167	990	153	6	83	236
10–11	1,064	164	$\frac{3}{4}$	10	174	1,010	156	$6\frac{1}{2}$	92	248
11–12	1,092	168	$\frac{1}{2}$	8	176	1,030	158	$6\frac{1}{2}$	94	252
12–13	1,122	173	0	...	173	1,052	162	$6\frac{1}{2}$	96	258
13–14	1,153	178	0	...	178	1,074	165	6	90	255
14–15	1,185	182	0	...	182	1,095	168	6	92	**260**
15–16	1,219	188	$\frac{1}{4}$	4	192	1,120	172	5	78	**250**
16–17	1,256	193	$\frac{1}{2}$	9	202	1,147	177	$4\frac{1}{2}$	73	**250**
17–18 18–19 19–20	1,294	199	$\frac{3}{4}$	14	213	1,175	181	4	66	**247**
20–21	1,387	213	...	...	**213**	1,244	191	...	...	191
H	**914**	...	...	...	...	865	...	...	...	...

IN LEFT SEMI-ARCH.

the Total Direct Thrust (T). ($A_1 = T \div 6{\cdot}5$).

the bending action. ($A_2 = \frac{\delta}{y'} . A_1$, and $A =$ A_2).

D.

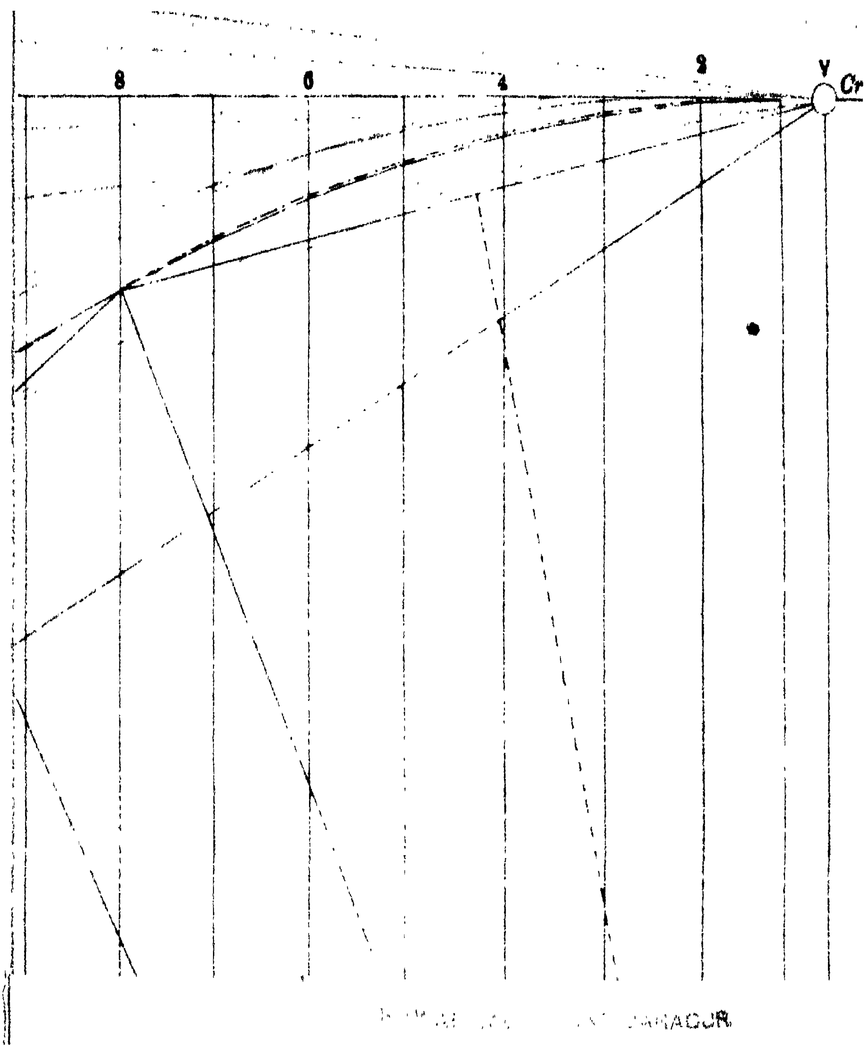
Load on ⅓-span from left. / Load on ⅔-span from right.					Load on ½-span from left.				
T	A_1	δ	A_2	A	T	A_1	δ	A_2	A
802	123	...	...	123	716	110	...	...	110
802	123	...	...	123					
810	125	5½	63	185	724	111	3½	35	146
831	128	6	70	198					
880	135	8½	104	239	777	120	10	109	229
886	136	8½	105	241					
904	139	9	113	253	802	123	11	123	246
903	139	8	101	240					
932	144	6	118	262	827	127	11	127	254
922	142	7	90	232					
962	148	8	108	256	857	132	11	132	264
942	145	7	92	237					
994	153	8	111	264	889	137	10½	131	268
962	148	6½	88	236					
1,027	158	7	101	259	922	142	9½	123	265
984	151	6	82	233					
1,000	163	6	89	252	956	147	8½	114	261
1,005	155	5½	78	233					
1,098	169	6	92	261	993	153	7	97	250
1,030	159	5	72	231					
1,137	175	4	64	239	1,033	159	6	87	246
1,057	163	4	59	222					
1,177	181	3	49	230	1,075	165	4½	68	233
1,085	167	3	46	213					
1,278	197	...	...	197	1,176	181	...	...	181
1,155	178	...	...	178					
797	...	...	...	...	714	...	...	...	...

SHEARING FORCES (F), AND STRESSES IN BRACES (R).

[*See* Steps IX, X, Chap. III].

[R = F. cosec *i*]. **F.**

Point.	Full Load. F	Full Load. R		Load on ¾-span R. F	Load on ¾-span R. R		Load on ¼-span L. / Load on ¼-span R. F	R		Load on ¼-span L. F	Load on ¼-span L. R
0	0			25			-82 81	123 122		-37	
1											
2											
3											
4	30			66			-20 71			-29	
5											
6											
7											
8	4			32	48		-6 9			-30	45
9											
10											
11	30			23			42 8			29	
12											
13											
14	34			0			64 -7			62	
15											
16	28			-20			69 -18			76	
17	27			-25			74 -21			85	
18	26			-31			76 -25			90	135
19	11			-47			67 -38			84	
20	-12			-71			49 -58			69	
21	-35			-92	138		27 -79			50	



8
6
4
2
V
Cr

DETAI	AREAS	Partial Moments about neutral axis $\Sigma\left(bd\,.\,\bar{y}\right)$
Vertic Cheel	4 = 30·0	30 × 132″ = 3,960·0
Horizo Outer F	8 = 15·0	15 × 140″·7 = 2,110·5
Angle-Irons. Outer: Ho F	$\frac{5}{8}$ = 3·75	·375 × 141″·3 = 529·875
Angle-Irons. Outer: V F	$\frac{9}{8}$ = 2·96875	2·969 × 142″·8 = 423·9732
Angle-Irons. Inner: Ho F	$\frac{5}{8}$ = 3·75	3·75 × 122″·7 = 460·125
Angle-Irons. Inner: V F	$\frac{9}{8}$ = 2·96875	2·969 × 121″·2 = 359·8428
TOTA for one F	58·4375	7,844·3160
Total Moment of for one f		

tance of centre of gravity
f one flange from neutral
xis of section.

$$\Bigg\} = \bar{y} = \frac{7{,}844{\cdot}3160}{58{\cdot}4375}$$

$$= 134''{\cdot}234$$

$$= 11'{\cdot}186$$

EFFECT OF WIND-PRESSURE.

[*See* Art. 2, Chap. IV].

H.

Number.	DATA. [taken from Diagram E]. Radius.	Semi-chord.	Semi-arc.	Rise.	Slope.	Calculation for centre of gravity of arc.				WIND PRESSURE.	EFFECTS OF WIND PRESSURE. Bending Moment.	Vertical Pressure.	Inner Rib.	Outer Rib.	Normal Pressure. Inner Rib.	Outer Rib	Shearing Force. Inner Rib.	Outer Rib.
	R.	ξ.	s.	k.	θ.	ξ ÷ s.	$\left(1-\frac{\xi}{s}\right)$	$R\left(1-\frac{\xi}{s}\right)$	$\bar{x}$.	P.	$M = P.\bar{x}$.	[illegible] Q.	$\frac{1}{3}$ Q.	$\frac{2}{3}$ Q.	$\frac{\frac{1}{3}Q}{\sin\theta}$.	$\frac{\frac{2}{3}Q}{\sin\theta}$.	$\frac{\frac{1}{3}Q}{\cos\theta}$.	$\frac{\frac{2}{3}Q}{\cos\theta}$.
0	369	Nil	Nil	Nil	Nil													
1		10·0	10·0															
2		28·5	28·5															
3		50·5	50·5															
4	369	72·5	72·5	6·5	11°½	1·000	Nil	Nil	6·5	28·5	185·25	1·4	·5	·9	·1	·2	·5	·9
5		94·5	94·5															
6		115·8	116·5															
7		137·2	138·5															
8	369	158·2	160·5	34·6	25°½	·986	·014	5·2	29·4	63·1	1,855·14	14·0	4·7	9·3	2·01	4·02	4·24	8·42
9	618	178·6	182·5															
10		198·8	204·5															
11	618	218·2	226·5	67·3	31°¾	·968	·037	22·9	44·4	89·0	3,951·60	30·0	10·0	20·0	5·26	10·52	8·5	17·0
12		237·0	248·5															
13		255·8	270·5															
14	618	273·4	292·5	105·5	38°	·935	·065	40·2	65·3	114·9	7,502·97	56·9	19·0	38·0	11·7	23·4	15·0	29·9
15		290·8	314·5															
16		307·0	336·5															
17	618	323·0	358·5	148·6	44°	·901	·099	61·2	87·4	140·8	13,305·92	93·2	31·1	62·2	21·6	43·2	22·3	44·7
18		337·6	380·5															
19		351·8	402·5															
20		363·0	421·0															
[illegible]	[illegible]	[illegible]	431·0	200·0	50°½	·858	·142	87·756	112·2	169·3	18,995·46	144·0	48·0	96·0	37·0	74·1	30·5	61·1

EFFECT OF WIND-PRESSURE.

[*See* Art. 2, Chap. IV].

H.

Number.	DATA. [taken from Diagram E].					Calculation for centre of gravity of arc.				WIND PRESSURE.	EFFECTS OF WIND PRESSURE.							
	Radius.	Semi-chord.	Semi-arc.	Rise.	Slope.						BENDING MOMENT.	VERTICAL PRESSURE.			NORMAL PRESSURE.		SHEARING FORCE.	
													Inner Rib.	Outer Rib.	Inner Rib.	Outer Rib	Inner Rib.	Outer Rib.
	R.	ξ.	s.	k.	θ.	$\xi \div s$.	$\left(1-\frac{w'_m}{w}\right)$	$R\left(1-\frac{w'_m}{w}\right)$	$\bar{x}$.	P.	$M = P.\bar{x}$.	Q.	⅓ Q.	⅔ Q.	⅓ Q sin θ.	⅔ Q sin θ.	⅓ Q cos θ.	⅔ Q cos θ.
0	369	Nil	Nil	Nil	Nil													
1		10·0	10·0															
2		28·5	28·5															
3		50·5	50·5															
4	369	72·5	72·5	6·5	11°½	1·000	Nil	Nil	6·5	28·5	185·25	1·4	·5	·9	·1	·2	·5	·9
5		94·5	94·5															
6		115·8	116·5															
7		137·2	138·5															
8	369	158·2	160·5	34·6	25°½	·986	·014	5·2	29·4	63·1	1,855·14	14·0	4·7	9·3	2·01	4·02	4·24	8·42
9	618	178·6	182·5															
10		198·8	204·5															
11	618	218·2	226·5	67·3	31°¾	·968	·037	22·9	44·4	89·0	3,951·60	30·0	10·0	20·0	5·26	10·52	8·5	17·0
12		237·0	248·5															
13		255·8	270·5															
14	618	273·4	292·5	105·5	38°	·935	·065	40·2	65·3	114·9	7,502·97	56·9	19·0	38·0	11·7	23·4	15·0	29·9
15		290·8	314·5															
16		307·0	336·5															
17	618	323·0	358·5	148·0	44°	·901	·099	61·2	87·4	140·8	13,305·92	93·2	31·1	62·2	21·6	43·2	22·3	44·7
18		337·6	380·5															
19		351·8	402·5															
20		363·0	421·0															
21	618	370·0	431·0	200·0	50°½	·858	·142	87·756	112·2	169·3	18,995·46	144·0	48·0	96·0	37·0	74·1	30·5	61·1

Calculation of Abscissa of Centre of Gravity of Unloaded Rib.

Number.	Abscissæ.*	Unloaded Rib.		
	From springing.	Loads.†	Sums of Loads.	Moments.
0	370·0	10·0	10·0	3,700·00
2	360·0	13·5	23·5	4,860·00
1	341·5	16·3	39·8	5,566·45
3	319·5	17·0	56·8	5,431·50
4	297·4	17·1	73·9	5,085·54
5	275·5	17·2	91·1	4,738·60
6	254·2	17·3	108·4	4,397·66
7	232·8	17·4	125·8	4,050·72
8	211·8	17·7	143·5	3,748·86
9	191·4	17·9	161·4	3,426·06
10	171·2	18·1	179·5	3,098·72
11	151·8	18·2	197·7	2,762·76
12	133·0	18·2	215·9	2,420·60
13	114·2	18·3	234·2	2,089·86
14	96·6	18·5	252·7	1,787·10
15	79·2	18·8	271·5	1,488·96
16	63·0	20·0	291·5	1,260·00
17	47·0	21·2	312·7	996·40
18	32·4	21·2	333·9	68[illegible]·88
19	18·2	20·5	354·4	373·10
20	7·0	17·7	372·1	123·90
Totals,		372·1	..	62,093·67
Abscissa of centre of gravity.	166·9			

* As in Calculation-Sheet B.

† Furnished by Designer.

ADDENDUM BY AUTHOR.

It has been pointed out* to the Author since the submission of this Report, that two of the assumptions made therein are incorrect, *viz.*,

(1). The crown is assumed to be a *fixed* point;

(2). The Loads are assumed to be applied at *fixed* horizontal distances from the springing, and that the correct condition to assume would be, that the neutral curve of the Rib undergoes distortion subject to condition

Either, 1°—that each chord of the neutral curve is of fixed length, (neglecting the compressibility of the material);

Or, 2°—that each chord of the neutral curve is compressed proportionally to the Thrust therein.

It must be freely admitted at once that the Conditions (1) and (2) assumed in the Essay and in the calculations based thereon are incorrect, and the Result 2 therefore faulty, and that Conditions 1° and 2° are the correct ones to adopt.

The assumptions (1) and (2) were adopted solely on account of the simplicity of the mathematical work resulting from them.

Thus in consequence of assumption (2), the calculation of the Moments of the Loads is easy, and in consequence of assumption (1),—(taken with the condition of free joints at crown and at both springings),—the Equilibrium-Curves can be easily drawn. This falls entirely within the principles of *elementary Statics.*

If the distortion of the Rib be considered, an immense complexity at once results, for the Loads being no longer applied at fixed points, their positions and their Moments can only be found by an indirect and difficult process, being in fact implicitly determined by Conditions 1° or 2°. It is no longer a problem of *simple* geometry and *simple* mechanics. The Equilibrium-Curves also can no longer be drawn by any elementary process. The introduction of the com-

* By Mr. E. H. Stone, Asst. Consultr. Engineer to Govt. for State Railways.

pression of the Rib (as in 2°) would introduce a further great increase of complexity.

These assumptions are also generally accepted at the outset by all authorities, *e.g.*,

(i). *See* M. Gaudard's Paper No. 1224 of Vol. XXXI. of Proceedings of Inst. of Civil Engineers, Art. 12 (on page 84), where the phrase

"The calculations * * * * * * * * * * would be simple and certain" shows at once that these assumptions are adopted.

(ii). *See* Mr. Bell at pages 143 to 148 of same Vol., who makes same assumptions.

(iii). *See* Rankine's Civil Engineering, 6th Ed., page 541, Case IV, (which is case of present arch): his mode of working out his Results involves same assumptions.

(iv). *See* Mr. Bell at page 79, Vol. XXXIII. of Proceedings of Inst. of Civil Engineers, who—so far as the cases coincide—makes same assumptions, *viz.* No. (2).

The adoption of a process is not of course justified by its simplicity, nor even by general adoption, unless it is known *à priori* (or can be shown) that the approximation is sufficient.

Let it be noted then, first with reference to the distortion of the Rib, that the points of application of the Loads will move only slightly, so that their Moments will change only slightly, and their Resultant Moment will change but little. Similarly the Total Stresses will only be slightly altered by this slight shifting. In face of the *uncertainty of the data* (the magnitudes of the Loads themselves) the errors in these quantities are (in the Author's opinion) probably not worth considering.

Next as to the Equilibrium-Curves: these will also be distorted with the shifting of the points of application of the Loads, and—in a certain sense—may be expected to follow the distortion of the "neutral curve."

But the separation of these curves, *i.e.*, of any Equilibrium-Curve and the neutral curve in their distorted state will not of course be the same as if they were undistorted: and it is quite uncertain *à priori* whether the variation of this separation will be a *relatively small quantity* or not, *i.e.*, very small compared with the separation which is itself a small quantity: or in other words, whether the Error in estimating the separation is small.

And it is upon this separation mainly that the BENDING MOMENTS (a different quantity from the Moments of the Loads above quoted) and STRESSES due to unsuitability of figure of the Neutral Curve depend.

And herein accordingly the numerical Results in this Report, based on assumption of Conditions (1) and (2), cannot be said with any certainty *à priori* to be sufficiently approximate.

Considering the great size and costliness of the Bridge in question, it would be right to re-examine this.

The mathematical work involved would of course no longer be simple, and the calculations would certainly be very laborious.

A. C.

No. CCXCVIII.

EXACTION OF TASKS ON RELIEF WORKS.

By J. A. Willmore, Esq. C.E., *Exec. Engineer.*

The difficulty experienced in exacting tasks from the different classes on relief works has been very clearly shown in Mr. Elliott's Report on the Mysore Famine, and as no details are there given, it may be of use to those who may hereafter have charge of such works to know how it was carried out by the Engineer officers, with a very fair amount of success in the Lucknow Division.

We had nothing like the supervising staff allowed in Mysore, which (Chap. V., page 72) appears to have consisted of a Civil officer for each work for general duties, and for the actual work, a Sub-Overseer for every 1,200, an Overseer for every 2,400, and a Sub-Engineer or Assistant for every 4,800 coolies; here, there were no Civil officers attached to works, and the staff for each work consisted of a Public Works officer in charge, and a Civil Subordinate such as a Peshkar, Schoolmaster or other available person to make payments, so that all classing, ganging, hutting, conservancy and the thousand and one details of a relief work had to be attended to by the Public Works officer.

Only one work in the Division was in charge of an Assistant Engineer, all the rest being under charge of Overseers and Sub-Overseers, who as a rule worked most creditably, one native Overseer having had at one time as many as 10,000 people on his work, from the bulk of whom tasks were exacted, and that they were fairly treated is proved by the fact that most of his people accompanied him from one work to another 20 miles off, when the first was completed.

In the Barabanki District the unit for measurement was for the greater part of the time, one beldar and his coolies, so that idleness was brought home to the actual culprit, this of course is most desirable and is commented on in page 80, Chapter V. of the Mysore Report, but the labour of measuring up in such detail is very great and takes up much time, and the Famine Commissioner and the Chief Engineer on visiting the works considered it unnecessary, and decided that the gang should form the unit of measurement.

The nominal roll system by which every person's name, &c., is written down when they first come, and they are placed in the same gang day after day, (*see* para. 36, Chapter V., Mysore Report,) was tried and failed, for the reasons that people did not come to the work every day regularly, that it took so long to pick out each person's name from a long roll of thousands, that half the day was lost in writing up the rolls, and the Public Works officer had no time for laying out work ahead of the working gangs, and this in road work, where the work advances rapidly, threw every thing into confusion.

The muster roll system described in the following rules was adopted and worked well, having failed only in one instance, where owing to neglect on the part of the Imprest holder, money had not arrived at pay time, the recurrence of this was obviated by the order for nominal rolls to be prepared whenever rain threatened or money was likely to be insufficient; the muster rolls formed daily cash and work vouchers, and no other accounts were required from the officers in actual charge, as from these the District Engineer could prepare all the returns and accounts required by Government and by the Accounts Department.

Exception may be taken to the order that only 6 inches of earth is to be taken from excavations, on the score that the top and presumably the best soil will be removed from a large area. To this I can only say that I have just been over one of the roads completed last June, and the whole of the excavations in culturable ground are under crops and undistinguishable from the rest of the fields, and on another road where the excavations were in jungle, the ground excavated has for the first time been brought under cultivation, whereas had deep excavations been made, the revenue of so much land would have been permanently lost to Government.

The rules that follow are those which were drawn up by me for the guidance of the officers of my Division when relief works were first started, modified as experience directed from time to time. They were found to be practicable and easily understood and worked by Native Public Works Subordinates, of whom I had no less than 10 in independent charge of works. I do not for a moment suppose they are the best obtainable, but they have proved practicable, which is something to say and may be of use to others.

Setting out work.—Before any work is started at least half a mile is to be laid out, and the laying out must at all times be kept well ahead of the working parties, a special gang should be kept on this work, and the Public Works officer in charge should give a certain portion of his time to it each day, as on its proper performance depends whether tasks can be exacted easily or not.

Pegs properly levelled will be given at 50 feet intervals or nearer if necessary; in embankments the profiles will be marked out with bamboos and string, and as these are liable to be removed, earth should be thrown up at each profile as quickly as possible and worked to the proper section, as a permanent guide for the working parties; in cutting the section will be given at 50 feet intervals, by cutting trenches 2 or 3 feet wide right across, the outer edges of embankments or cuttings and outer and inner edges of side drains are then to be *daghbeled.*

Where the earth from side drains will not give what is requisite to raise the road, it will be obtained by excavating from land along side or from any waste ground near, *avoiding sand or oasur;* such excavations will be only 6 inches deep, and the inner edge should not be less than 4 feet from the outer edge of side drain; the width of the excavations required should be roughly calculated and *daghbeled* out in 10 feet lengths.

Receiving and classifying labourers.—All who come and are fit to do any work are to be received up to 9 A.M., and the Public Works officer will separate them into the following four classes.

Class I.—Able-bodied, who will be required to do a full task, or 75 per cent. of what an ordinary labourer can do.

Class II.—Those who can do only half of the above task.

Class III.—Those who can do only one-quarter of the full task.

Class IV. or special gang of aged and weakly, able to do light work only, these will not be tasked.

People who from age or sickness are unable to do any thing will be sent either to the poor house or hospital ; the greatest possible care should be exercised in classing, and when there is any doubt as to the class, the person should be placed in the lower.

The classes are to be kept quite separate on the work.

Ganging.—This may be most conveniently and speedily done when classing, the people being classed and ganged at one and the same time. Gangs should consist of from 10 to 15 beldars and a sufficient number of coolies, but no gang should contain more than 100 persons; no men should be allowed to do coolies work until sufficient beldars have been obtained to employ all the women and children. Each gang shall be under a mate, who should be selected from the people. The mate will be responsible for keeping the numbers of his gang together, and for the tools supplied, and when the gang is formed, his name, the number of men, women and children forming his gang, and the tools issued, will be entered in the muster roll by the writer of the section.

Each gang as formed will be told off to the work and shown what to do and how to do it, some good mistries being employed for this purpose.

Measuring up.—Will be done by the Public Works officer assisted by his mistries every afternoon for each gang, and this, if the setting out has been properly done, will be a very simple matter, as only the length will have to be measured, and the depth (6 inches) tested ; as each gang's work is measured, all *matams* and irregularities should be cleared off, and the excavation left square right across, so that work can start fair next day, any gang not doing the allotted task are to get the minimum wage.

Paying.—The wages earned by each gang will be entered by the Public Works officer in the muster roll of the gang, which will be made over to the paying officer, who will always be a Civil officer or subordinate appointed by the Magistrate of the District, and unconnected with the Public Works Department; and one such paying officer will be required for every 2,000 people. At pay time the writer of the section will accompany his gangs and see that the tools issued as entered in muster roll are all returned before any payment is made. The gangs will be made to sit down, the muster rolls will be given to the paying officer, who after paying will enter the amount actually paid and return the muster roll to the Public Works officer as his cash voucher.

Paying should commence not later than 5 P.M., and be completed by

7 P.M., *i. e.*, 2,000 people should be paid easily by one person in two hours.

Scale of wages.—Will be fixed by the District Engineer under the Magistrate's orders, for each work according to the price of grain; the wages for each rate and class will be found in the printed table attached to G. O. No. 1301 A.C., dated 12th September, 1878. The District Engineer will give the rates in writing to the officer in charge of each work.

Nominal Rolls.—If from any cause such as likelihood of rain or insufficiency of money (this latter cause is invariably to be reported and explained to Executive Engineer), it is feared that payment cannot be made the same day, nominal rolls in the form attached must be prepared by the writers *as soon* as the gangs have been got to work. The muster rolls will be prepared as usual.

Nominal rolls must also be prepared the day before the weekly holiday.

Sundays and Holidays.—Sunday will not always be a holiday, one day of rest will be given each week, and Sunday should be selected as often as possible without letting it be a regular thing; the day before the rest day, nominal rolls will be prepared and made over to the paying officer who will pay those entered, if they are present at the time appointed, persons presenting themselves for the first time on a rest day should only be taken on if in great distress, and should then receive the minimum wage only.

Amount of tasks.—The District Engineer will fix the task for each according to the soil and season, the following details are given as a general guide:—

In May in fairly hard soil a beldar of Class I. dug 200 cubic feet in a day, and this was increased in August, after rain to 250 cubic feet.

The number of coolies to each beldar will depend on the lead; a strong woman carries 100 cubic feet of earth in 225 baskets, and a child of 10 to 12, in 480 baskets, the distance allowable for a strong woman is 12 miles per day, so that with a lead of 100 feet, a strong woman is required for every 150 cubic feet dug, but as on relief works only 75 per cent. of an ordinary day's labour is to be taken from Class I. It follows that, for—

50 feet lead one woman is required for 225 cubic feet dug.
100 „ two „ are „ „ „

For the other classes the numbers must be doubled and quadrupled.

In fixing tasks care must be taken not to make them too heavy at first, but to work up to what is considered a fair task, giving notice the previous day of each increase.

Petty Establishment.—A writer to write up muster rolls, nominal rolls and assist in ganging, &c., will be allowed for every section of 500 people, and for every 2,000 people, one extra will be allowed to look after the tools, see to their repairs, and the accounts of the repairs gang, which he will also act as mate of, these men will get Rs. 10 to 15 a month.

One mistri capable of laying out and supervising the work will be allowed to every 500 people, these mistris will get from Rs. 8 to 15.

Accounts.—The officer in charge will keep his Imprest Cash Book and Daily Report Forms according to Code Rules, they are to be written up every day and submitted to District Engineer as often as he may order, the only other accounts to be kept by the officer in charge of the work are the Muster and Nominal rolls in forms attached.

From these accounts the District Engineer will be able to prepare the Monthly Day Books and the Weekly Returns of numbers and cost, and the Monthly Nominal rolls which have to be submitted to Government.

Supply of Money.—Funds will be allotted to the District Engineer, who will arrange with the Magistrate of his District for a sufficient supply of copper money; each officer in charge of a relief work should be an Imprest holder, having an imprest sufficient for at least three day's payment. The Imprest holder will each day supply the paying officer with the money required for payment, and will enter the amount actually paid in his Cash Book, attaching the Muster roll or Nominal rolls as vouchers, and sending his Imprest Cash Book to the District Engineer for recoupment as often as ordered.

__________ Division.
__________ District.

Muster Roll for __________ 187 .

Name of Work __________

Name of Mate	Detail of Gang: Men at: No.	Men at: Amount	Women at: No.	Women at: Amount	Children at: No.	Children at: Amount	Total amount	Amount actually paid	Tools issued: Phaoras	Tools issued: Baskets	Class of each gang	Task due	Quantity actually done	Remarks

Date ______ Total Rs. ______

Sd. ______ Paying Officer. Sd. ______ P. W. Officer in charge.

Nominal Roll.

__________ Division.
__________ District.

Name of Work __________

Name	Father's Name	Caste* and Religion	Residence by Districts	Rate of pay	Remarks
			Men. Women. Children.	This column to be filled up by paying officer at time of payment.	

Date ______ Total Rs. ______

Sd. ______ Paying Officer. Sd. ______ P. W. Officer.

* After Caste put M for Mahomedan H for Hindus.

No. CCXCIX.

BOAT BRIDGE OVER THE RIVER RAVI AT CHICHAWATNI, PANJAB.

[*Vide* Plates I.—III.]

BY RAI BAHADUR KUNHYA LALL, *Assoc. Inst. C.E., Exec. Engineer, P. W. Dept., Panjab.*

THE above boat bridge was formerly *straight*, of the old usual construction, *viz.*, boats supported against the stream by munj cables and anchors.

In the heavy rains of 1876 it was swept away, and was reconstructed in 1877, in a new *curved* form with boats supported on a strong iron chain, without any anchors in the river on the up-stream side.

It has eight anchors, or one to every alternate boat, on the down-stream side with munj cables, and about 20 feet of $\frac{3}{4}$-inch chain to each at the end, attached to the boat to prevent the bridge being blown up against the river by high winds.

Plate No. I. shows the present general form of the bridge, and *Plates* Nos. II., III., contain the constructive details.

The up-stream chain is a one inch short linked iron chain called "crane chain," and the down-stream chain a $\frac{3}{4}$-inch stud chain.

The bridge consists of 16 boats in the cold weather, and 18 boats in the rains. The boats are large, of standard pattern, and the superstructure is also of standard pattern, on plan and specification published in Roorkee Professional Papers, *see* Vol. IV. of 1st Series, Paper No. CLXVIII.

The ends of the trussed girders are cased with sheet-iron, *see* figure 7, *Plate* No. III., to protect them against rapid wear and tear.

The chains are fastened to the boats at bow and stern, by means of stout wooden blocks and iron forks, *see* figures 8, 9, 10 and 11, *Plate* No. III.

The ends of the up-stream chain are secured to a mass of concrete of a trapezoidal shape, 10 feet wide at the back, 15 feet at the front, or towards the river, 16 feet long, and 12 feet deep, *see* figures 2, 3 and 4, *Plate* II.

The mass of concrete has a rectangular hole in it, 3 feet high, and 1 foot wide, through which the chain is passed, and fastened to a stout block of wood 7 feet long, 12 inches wide, and 18 inches deep, placed horizontally at the back of the mass of concrete, which is made at right angles to the direction of the chain, and secured to it by means of strong iron bolts attached two other pieces of wood, laid vertically on the surface of the concrete, as shown in the figure. The chain is wrapped round the block of wood two or three times, and the end links fastened to other links of the chain, by means of thin telegraph wire, in two or three places.

The semi-circular well at the back of the mass of concrete admits of this fastening being examined and re-adjusted whenever necessary. The ends of the horizontal block of wood to which the chain is fastened are built 6 inches on either side into the masonry of the well, and the open space between the block and the surface of the concrete is filled with short pieces of wood, bolted to the vertical pieces.

Each end of the down-stream chain is firmly moored to an iron anchor, secured in its place, 5 to 6 feet under ground, by means of six strong pieces of wood laid against it, at right angles to the direction of the chain.

The chain is wrapped round the iron anchor, and the end links fastened in two or three places to the other links of the chain, with thin telegraph wire, in the same way as the up-stream chain.

The upper chain, which is 1 inch in diameter, is tested to 16 tons, and has a breaking strain of 32 tons.

The maximum strain to which it is subjected in the bridge during heavy floods is about 8 tons, which is its safe working load, so that there is no fear whatever of its giving way.

The efficacy of this chain was fully tested in the heavy rains of July and August 1878, when heavy floods came down the river, and subjected the chain to an unusual strain. The chain stood perfectly safe, and the bridge was maintained and kept open for traffic throughout the floods.

The lower chain has a proof strength of 8 tons, and breaking strength of 16 tons.

The strain on the upper chain is calculated as follows:—

It has been found, from actual experiments, that the tension of one bridge boat, loaded with superstructure of one bay, is about 60 lbs. in a velocity of 3 feet per second. Of the 18 boats in the bridge during the rains, 6 boats in the middle, or in the strongest current, are subjected to a velocity of about 10 feet a second, 6 to a velocity of 7 feet a second, 4 to a velocity of 5 feet a second, and 2 to a velocity of 3 feet a second. Now the strains in different velocities vary as the squares of the velocities, therefore,

The strain on the middle 6 boats is equal to	$6 \times \frac{10^2 \times 60}{3^2}$	=	4,000 lbs.
Ditto on other 6 boats	$= 6 \times \frac{7^2 \times 60}{3^2}$	=	1,960 „
Ditto on 4 boats	$= 4 \times \frac{5^2 \times 60}{3^2}$	=	666 „
Ditto on 2 boats	$= 2 \times 60$	=	120 „
	Total	...	6,746 lbs.
Add for waves at one-fourth of above		=	1,686 „
Pressure of wind, in a hurricane, at 400 lbs. per boat and superstructure of one bay	$= 18 \times 400$	=	7,200 „
	Total strains	=	15,632 lbs.
		=	7 tons nearly.

Now the strain in the middle of the chain is $S = \frac{C \cdot L}{8V}$.

Where L = weight,

C, the chord or span, and

V, the versed sine.

If the versed sine were made one-eighth of span, then S = L.

In the case of the Chichawatni boat bridge,

L = total strain on the bridge.

= 7 tons.

C = 644 tons.

V = 80 tons.

Therefore S, or strain in the middle of the chain = L = 7 tons.

Strain on the chain at each end = S × sec of angle of chain with the span, (which being 27°) = 7 × 1·12232

= 7·856 tons.

Therefore the maximum strain on the chain is 7·856 tons. Its safe working load being 8 tons, or half the proof strength, it is quite strong enough to support the bridge. The lower chain also adds 4 tons to the safe working load of the upper chain, so that the bridge is perfectly safe, even if a heavy flood and strong wind came upon it from the up-stream side, a contingency which can seldom, or never, happen.

The above form has been adopted for this bridge, owing to the river at Chichawatni being confined between two bold and defined banks.

The advantages of this construction over the old system of supporting boats with munj cables and anchors, are cheapness and permanency.

Bridges on the old plan require temporary anchors and cables, which involve constant renewal and consequent serious expense. The anchors also often fail to hold, owing to the shifting nature of the beds in many of the rivers. Besides grass rubbish, branches of trees, floating logs, and wrecks of boats, &c., coming down the river, especially in floods, catch on the cables, which, when the anchors hold, become so deflected as to be actually vertical, causing the bows of the boats to be deeply buried towards the up-stream side, which subjects the bridge to severe strains. This was very much felt at the boat bridge at Shahdera during heavy floods, so much so, that the bridge, when on the old plan, caused very serious inconvenience, and sometimes gave way, leading to the loss of a great portion of superstructure, and sometimes of boats also.

The old bridge at Shahdera has also been replaced now with a bridge in the new *curved* form exactly similar pattern to that at Chichawatni, but at Shahdera, the river being wider, there are 24 boats in the bridge and the length of the crane chain supporting the boats is 1,300 feet.

The mode of construction is the same at both places.

In streams with low or shifting banks, the old plan is the only one that can be adopted, *viz.*, straight bridge, with boats supported on cables and anchors.

K. L.

LAHORE:

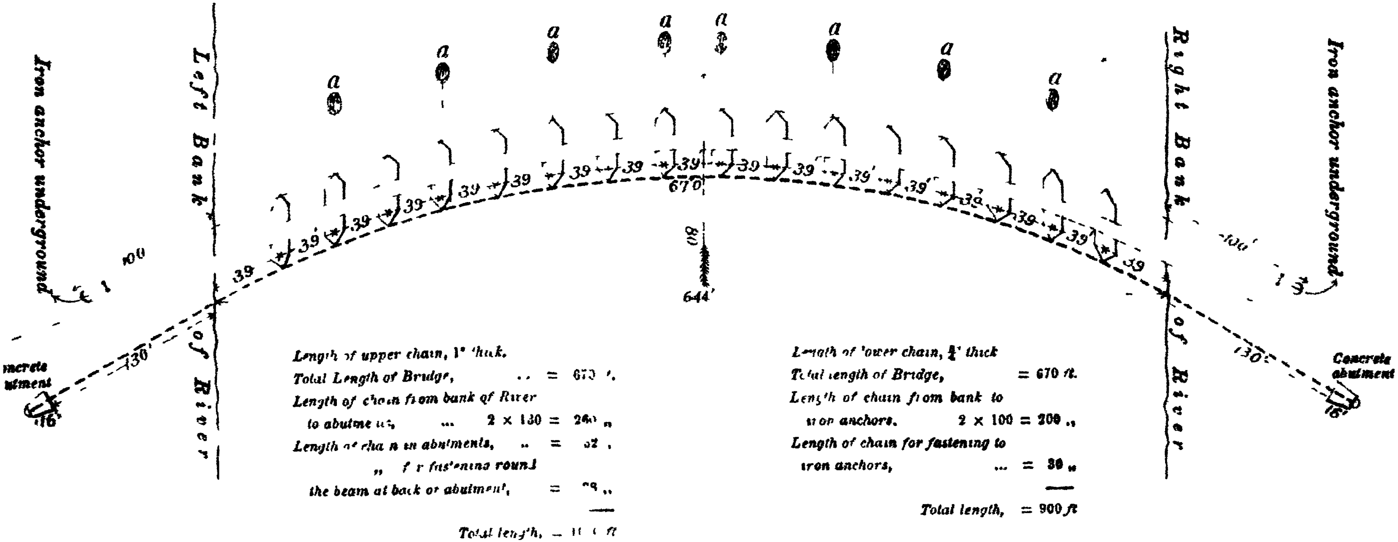
28th February, 1879.

BOAT BRIDGE OVER RIVER RAVI AT CHICHAWATNI.

Scale. 1 *inch* = 120 *feet.*

Fig 1.

PLAN OF BOAT BRIDGE CONSTRUCTED OVER THE RIVER RAVI AT CHICHAWATNI IN THE MONTGOMERY DISTRICT, PUNJAB.



SKETCH OF CONCRETE ABUTMENT FOR RAVI BOAT BRIDGE AT CHICHAWATNI IN MONTGOMERY DISTRICT.

SECTION

Fig. 2.

SECTION OF ABUTMENT.

Fig. 3.

PLAN OF ABUTMENT.

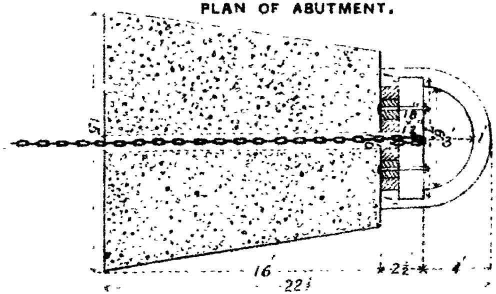
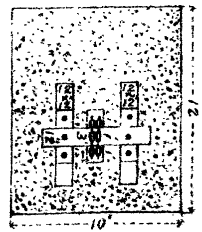


Fig. 4.

BACK OF ABUTMENT.



BOAT BRIDGE OVER RIVER RAVI AT CHICHAWATNI.

Scale. 1 *inch* = 10 *feet.*

BOAT BRIDGE OVER RIVER RAVI AT CHICHAWATNI.

Scale. 2 *inches* = 1 *foot for* Figs. 8, 9, 10 *and* 11.

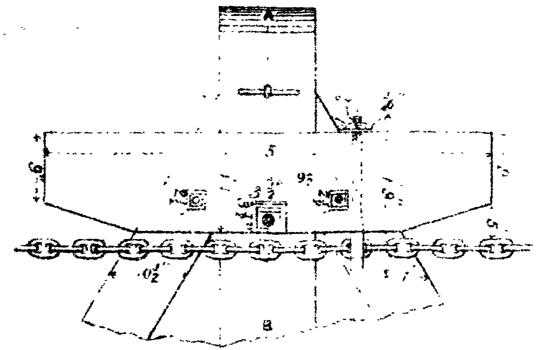
Scale. 1 *inch* = 2 *feet for* Figs. 5 *and* 6.

Scale. ¾ *inch* = 2 *feet for* Fig. 7.

ETCH SHOWING ARRANGEMENTS FOR FASTENING THE CONNECTING CHAIN AT THE BOW AND STERN OF BRIDGE BOATS.

Fig. 5.

PLAN



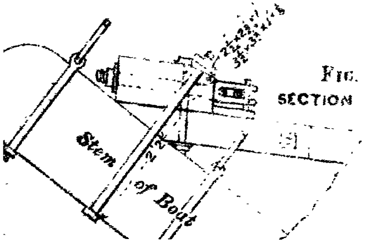


Fig. 6.

SECTION ON AB.

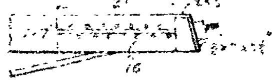


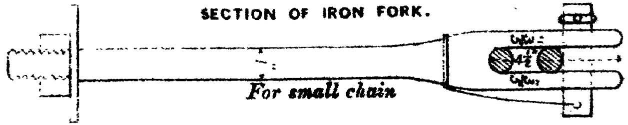
Fig. 7.

PLAN OF SHEET IRON CASING FOR ENDS OF TRUSSED GIRDERS.

DETAILS OF FORK AND KEY FOR FASTENING THE CONNECTING CHAIN, IN ENLARGED SCALE.

Fig. 8.

SECTION OF IRON FORK.



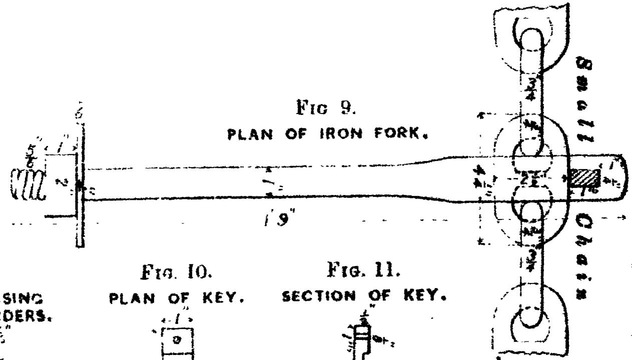


Fig 9.

PLAN OF IRON FORK.

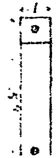


Fig. 10.

PLAN OF KEY.

Fig. 11.

SECTION OF KEY.

No. CCC.

HYDRAULIC MEMOIRS.

NEW RESEARCHES ON THE EXPRESSION OF THE CONDITIONS OF MOTION OF WATER IN DRAINS, BY M. POPOFF.

Report of a Commission of the French Academy of Science on the above. Commissioners: MM. de la Gournerie and de Saint-Venant (reporter).

Trans. by CAPT. ALLAN CUNNINGHAM, R.E., Hony. Fell. of King's Coll. London.

Translator's Preface.—The Report here translated is published in No. 20 of Vol. LXXXVII. of the *Comptes Rendus* of the French Academy of Science for 11 November 1878. As the Memoir is described as an important work, this warrants this introduction of it to the profession in India.

The Author of this considerable work, on which he wishes to have the opinion of the Academy, explains that the known formulæ for water in motion applied in the usual way give for sewers discharges much less than the actual* discharges; whence it follows that their habitual use tends to give for these subterranean conduits of urban waters dimensions or slopes far greater than what is necessary, and thus involves their administrations in ruinous expense.

He seeks therefore new solutions. Although his mode of solving questions concerning them may be matter of dispute, his work has the advantage of taking up several of them, of recapitulating little known results, and of presenting several practically useful considerations. It deserves therefore to be examined with care.

* He quotes on this point several English publications, such as the *Proceedings of the Institution of Civil Engineers*; *On the Main Drainage of London*, by J. Bazalgette; *Opinions of Messrs. E. Chadwick and R. Rawlinson*; and especially, *Sanitary Engineering, a guide of construction of works of sewage and house drainage*, by B. Latham, 1873.

The formulæ for uniform motion of water which he makes use of are those of Prony and Eytelwein, and especially those of Mr. Weisbach. It is convenient in the first place to collect these and to define their meaning.

It is known that if we style, with the usual notation,

ω the area and χ the wetted perimeter of the cross-section of a uniform current;

$U = \frac{Q}{\omega}$ its mean velocity, the quotient on division by ω of the discharge Q in cubic mètres per second;

L the length of a portion of an open channel, or of a pipe having its origin and its outfall in the water of two reservoirs;

h the fall or head, being the difference of level of the fluid surface at the two ends of the part L of the open channel, or of the surface-levels of the water in the two reservoirs which are joined by the pipe;

$I = \frac{h}{L}$ the *constant slope* per mètre of the open channel;

J, in the pipe, the *virtual slope*, playing the same part, and to which must be assigned the following value, so as to take account of the portion of the head h which is expended in impressing the mean velocity U in the pipe;

$$J = \begin{cases} \text{either} \left\{ h - \frac{U^2}{2g}\left[1{\cdot}11 + \left(\frac{1}{m} - 1\right)^2\right] \right\} \div L \\ \quad = \left\{ h - \frac{1}{2g}\left(\frac{U}{\mu}\right)^2 \right\} \div L, \text{ where } \mu = {\cdot}82, \text{ if } m = {\cdot}62, \\ \text{or} \left\{ h - \frac{U^2}{2g}\left[1{\cdot}22 + \left(\frac{1}{m} - 1\right)^2\right] \right\} \div L \\ \quad = \left\{ h - \frac{1}{2g}\left(\frac{U}{\mu}\right)^2 \right\} \div L, \text{ where } \mu = {\cdot}79, \text{ if } m = {\cdot}62, \end{cases} \quad (1),$$

according as the tube is only a short "adjutage", incapable of impressing on the stream-lines at their exit differences of velocity comparable with those which occur in each cross-section in a uniform motion, or according as it is on the other hand long enough for these differences to become fully* established.

It is known—I say—that if, Π being the weight of a cubic mètre of the fluid, we denote by $\Pi b_1 U^2$ the resistance of the sides per square mètre, then as $\Pi\omega I$ or $\Pi\omega J = X\Pi b_1 U^2$ is evidently the condition of

* Navier and Bélanger used to write between the brackets $1 + \left(\frac{1}{m} - 1\right)^2$ which gives $\mu = {\cdot}85$ instead of ·82 as given by experiments on "adjutages" (nozzles or delivery-pipes), when forming an equation of motion in which the half of the *vis viva* of translation lost in eddying action is $\frac{1}{2}\left(\frac{1}{m} - 1\right)^2 . U^2$ per unit of mass of fluid discharged, m being the coefficient of contraction at its entry into the pipe. M. Boussinesq has shown in a very plausible way, by the differences of velocity of different stream-lines, &c., the addition of ·11 or ·22 to be made—as the case may be—to the binomial between the brackets.

dynamic equilibrium of the fluid contained between two sections at unit distance apart, we have

$$\frac{\omega}{\chi}\,\mathrm{I}, \text{ or } \frac{\omega}{\chi}\,\mathrm{J} = b_1 \mathrm{U}^2, \ldots\ldots\ldots\ldots (2),$$

an equation in which b_1 is a coefficient of order -1, being the quotient of a number by a linear unit.

According to figures given in English feet ($=$ ·3048 mètre) in Mr. Popoff's Memoir, we have in mètres according to Weisbach,

$$\text{Open channels, } b_1 = \cdot 0003776 + \frac{\cdot 0000221}{\mathrm{U}}, \ldots\ldots\ldots\ldots (3),$$

or nearly as given by Eytelwein; and according to the same or to Mr. Bornemann,

$$\text{Pipes flowing full, } b_1 = \cdot 000191 + \frac{\cdot 0001207}{\sqrt{\mathrm{U}}} \ldots\ldots\ldots\ldots (4),$$

whilst Eytelwein proposes $b_1 = \cdot 000280 + \frac{[illegible]}{\mathrm{U}}$, or more simply,

$$b_1 = \cdot 000376 \ldots\ldots\ldots\ldots (5).$$

The author next quotes Mr. Weisbach as having given for calculating the velocity in a pipe under a head h the following which results from substituting the value (1) of J into (2), *viz.*,

$$\mathrm{U} = \frac{\sqrt{2\,gh}}{\sqrt{1 + \left(\frac{1}{\mu^2} - 1\right) + 2\,g b_1 \frac{\chi \mathrm{L}}{\omega}}} \text{ (where } \frac{1}{\mu^2} - 1 = \cdot 487, \text{ if } \mu = \cdot 82) \ldots (6);$$

an expression in which M. Weisbach suppresses the second of the three terms under the root if the sensibly still water of the upper reservoir enters into the pipe without contraction.

And in this he suppresses even the first term 1 if the water enters with the velocity U already acquired, or even if the length of the pipe is great enough to make the last term the most important, whence

$$\mathrm{U} = \sqrt{\frac{1}{b_1} \frac{\omega}{\chi} \frac{h}{\mathrm{L}}}, \text{ the same as (2) on substituting } \frac{h}{\mathrm{L}} \text{ for I or J, } \ldots\ldots (7).$$

After the above explanation, it is convenient—in order to give readily an idea of Mr. Popoff's work—to study the *examples* 1, 2, 3, 4, 5 which he gives at the end of his Memoir and the Appendix following.

In the *second example*, he inquires what would be the velocity of exit of the water from a sewer or large horizontal pipe having a length L = 410 mètres, and a circular section of 2·1336 mètres diameter, if the water be forced in horizontally with a velocity $\mathrm{U}_0 = 1^{\mathrm{m}}{\cdot}2192$ (4 feet) per second.

None of the known formulæ admit—says he—of this question being solved, for they are not applicable to canals or conduits without slope or without effective head. He solves it by forming an equation

$$\tfrac{1}{2}\,U_0^2 - \tfrac{1}{2}\,U^2 = \frac{\chi L}{\omega^2}\,gb_1U^2, \text{ ....} \quad (9).$$

which is of fourth degree in $\sqrt{U}$ after putting for b_1 the expressions (4) assigned by Weisbach, and he finds by means of a table previously calculated

$$U = U_0 \div \sqrt{1 + 2gb_1\frac{\chi L}{\omega}} = 1{\cdot}566 \text{ feet, or } {\cdot}477 \text{ mètre per second,} \ldots (10).$$

The Equation above found (9) amounts, on multiplying it by the mass $\frac{\Pi}{g}\omega U dt$ of fluid discharged in the time-element dt, to expressing that the half *vis viva* of the fluid entering the pipe is equal to the half *vis viva* of that which leaves it together with the work $\chi L\Pi b_1U^2Udt$ done against the resistance of the border in the same time. It would be exact if this resistance could be considered as having, from one end of the pipe to the other, the intensity which it would have if the velocity, the fluid section, and the wetted border were everywhere U, ω and χ; admitting moreover that the passage from the velocity U_0, to the decidedly less velocity U be made so gradually as to cause no eddying action, and no loss of *vis viva* of translation.

But if the decrease from U_0 to U is suddenly made, we shall remark that it would be necessary to somewhat increase the second member of the equation on account of this loss, and the equation would give a decidedly smaller value for U.

What would take place in this respect, *viz.*, the way in which the water would behave during its passage from the value U_0 to the value U of the velocity would certainly depend on the volume forced in, which does not appear in the equation, and which evidently could not all enter the pipe if its volume exceeded a certain quantity.

In the *third example*, the Author proposes to derive from theory, taking as example the main pipe of the left bank of the Seine, the discharge of $4^{m}{\cdot}63$, which he thinks may be taken from a Memoir* of our lamented coadjutor Mr. Belgrand, by supposing its total fall $1^{m}{\cdot}64$ distributed uniformly throughout its length of 5,339 mètres between the Bièvre and the Alma syphon, whereas Prony's and Eytelwein's formulæ only furnish a discharge below the half of this.

* Memoir on the main pipe of the Bièvre and on the Alma syphon.

To this end, and in order also to bring the theory into accord with four observations of discharge of pipes in London, which he quotes in his Appendix,* Mr. Popoff modifies radically the formula given by Navier, Bélanger, &c., for the velocity U assumed in a pipe under a head h.

In place of the last term $2gb_1 \frac{\chi L}{\omega}$ under the radical in the denominator he substitutes

$$4gb_1 \frac{\chi L}{\omega h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12).$$

so that whenever—as he has explained—the two first terms may be suppressed, there would be obtained the expression $U = h\sqrt{\frac{1}{2b_1} \cdot \frac{\omega}{\chi L}}$ which he uses in his examples instead of Eq. (7), $U = \sqrt{\frac{1}{b_1} \frac{\omega h}{\chi L}}$.

We shall not explain here the reasons given for this change, which makes the formulæ non-homogeneous, and in which we are unable to agree. But we decidedly approve the necessity which the Author shows of some modification.

We might seek to effect it by giving smaller values to the coefficient of resistance b_1; for if in place of that of about ·00038 assigned to it by Prony, Eytelwein, and Weisbach, we had taken for the Paris sewer $b_1 = ·00016$, which results from the more recent experimental researches of M. Bazin on channels with sides of polished cement, and if for three of the four London drain pipes of *stoneware* we had made use of Darcy's experiments on new cast-iron giving $b_1 = ·0003$, we should have obtained results rising to three-fourths and two-thirds of those given, as said, by experiment.

There is also much uncertainty in the slopes and sections, for not to mention that they are not constant in the Paris main, Mr. Belgrand has

* The examples quoted by Mr. Popoff are the following extracted, except the first, from a *to the Board of Health* in 1850 by Mr. Medworth.

	Slope I or J	Diam.	Section. ω	Perimeter. χ	$\frac{\omega}{\chi}$	$\frac{\omega}{\chi}$ I	Discharge ωU	Velocity U
		m.	m.	m.			m.	m.
Paris main, ...	·000807	...	3·126	6	·521	·00016	4·63	1·481
London: Sewer Pipe No. 1, ...	·01	·0762	·00456	·2394	·01905	·00019	·00548	1·190
London: " " " 2, ...	·01	·1016	·008108	·3192	·0254	·000254	·01085	1·3387
London: " " " 3, ...	·01	·1524	·01824	·4788	·0381	·000381	·02997	1·643
London: " " " 4, ...	·00125	·1524	·01824	·4788	·0381	·0000476	·02227	1·221

well remarked that when sewers discharge into the air and not into water, the slope of the fluid surface within may greatly exceed that of their floor, and the motion is thereby accelerated.

In the first example, the Author, estimating the quantity of water for domestic use passing from each house at *two millionths of a cubic mètre* per inhabitant per second, and adding the rain water, calculates the slope to be given to a pipe which shall lead them to the sewer in such a way that they may have as far as possible a velocity of at least ·9 mètres, which he describes as "self-cleansing". Sir Baldwin Latham had before remarked that to avoid frequent and difficult cleansings, it is better to give a much higher slope to the upper branch pipes than to the mains.

In the *fourth example*, he makes a similar calculation for the waters of a whole town such as Odessa.

In the fifth, the Author supposes that a main discharging a mass of water m is met obliquely by an affluent which carries a mass m'. He attempts to calculate the loss of head which results from this meeting. We consider it is not worth while exhibiting and discussing the method which he adopts for this; for we think that the desired results will be obtained in a more certain way by forming the usual equations, whether of quantities of motion or of the work expended in motion and in resistance, and of *vires vivæ* both impressed and acquired, in calculating by known theories the loss of each, especially where they change rapidly in magnitude.

To sum up, Mr. Popoff's Memoir of December 1876 shows very clearly, by citing a certain number of experimental facts the probable necessity of new formulæ for the calculation of the velocity in sewer mains, either by changing the known numerical coefficients, or by considering the motion of the water in these subterranean channels as being in general variable or non-uniform, &c.

He proposes several problems, the best solutions of which it is desirable that hydraulicians should seek. These are, recapitulating them here;—

1°. That of the velocity assumed in a long distributary supposed horizontal by water uniformly forced in with a higher velocity, distinguishing—if the case arise—the cases in which the decrease of velocity occurs quietly or gradually, from those in which it can take effect only suddenly or with disturbance, a matter which may depend on its volume; a problem which may serve as a preliminary to other more practical ones, and in which the small necessary afflux of the axis of the injected stream should be taken into consideration.

2°. That of the taking account more generally of an initial velocity or velocity of entry in pipes or mains having any slope whatever.

3°. That of the motion of water in a main receiving many affluents, continuous or temporary, with various slopes.

4°. That of the motion which occurs when a main or a pipe discharges wholly or in part in the air and not into water, which causes therein a depression making the motion variable.

Although Mr. Popoff has not given in a certain way the solution of these delicate questions, he has made himself assuredly most useful to Science and Art, by making and exhibiting novel considerations with quotations of facts which may lead to their resolution with greater certainty. We therefore recommend thanking him for his great work, and inducing him to collect and publish as many results of observation as he can, accompanying them with the detail of the circumstances connected, in order to furnish the elements of elucidation of the matters to which he has devoted his labour with so much perseverance and zeal.

A. C.

No. CCCI.

JAMNA RIVER SUSPENSION BRIDGE, CHAKRATA ROAD.

[*Vide* Plates I.—III.]

THE papers regarding the design, execution and testing of the above noted bridge have been sent for the Papers by the Inspector General, Military Works, at the kind suggestion of Sir Andrew Clarke. They are somewhat voluminous, but the following selections from the case will it is hoped prove interesting. No attempt to show detail has been made, only to give a general idea of the work.

The estimate for the bridge was made out by Major Browne, R.E., and submitted for sanction by Colonel A. Taylor, C.B., R.E., in December 1873, with the following Note.

Note by COLONEL A. TAYLOR, C.B., R.E., *Chief Engineer, Military Works, on the design for a suspension bridge over the Jamna River near Kalsie on the Saharanpur and Chakrata Road.*

The cart-road from Saharanpur to Chakrata crosses the Jamna in the 51st mile.

Area of catchment basin.—At this point the area of the catchment basin is 895 square miles (Surveyor General's letter No. 948 of 10th June 1872).

The bed of the river is composed of boulders, some of which are of very large size, measuring upwards of 100 cubic feet, and has a longitudinal slope at the rate of 35·9 feet per mile.

Surface velocity in floods.—The greatest actually measured surface velocity, of which we have information, is 15 feet per second, but it may be accepted that it occasionally is more than this.

Rise in floods.—The flood level shown is about 1½ feet above the highest of which we have reliable knowledge, but the discharge when the river is at this level is so greatly out of proportion to the area drained, that we must be prepared occasionally, though perhaps at long intervals, to encounter floods of much greater magnitude. The design meets this necessity, and the abutments are so arranged as to admit of their being turned by the river without the stability of the bridge being thereby endangered.

Site.—The site has been well selected by Major J. Browne, R.E. The stream here occupies the centre of the bed, which rises from the water on each side with a fairly uniform slope until it reaches the defined bank.

Existing suspension bridge in the neighbourhood.—Above the site a light suspension bridge for foot passengers and cattle was constructed some years ago, having a central span of 200 feet (from centre to centre of the piers) with a half span on each side. The distance from face to face of abutment being thus 400 feet. The southern of the two piers was undermined by the stream during the floods of 1873, and destroyed, and some little difficulty is experienced in keeping the river confined to the space between the two abutments.

Referring now to the design.

Suspension form why selected.—Foundations for a permanent bridge must in such a violent stream be costly and difficult of construction. Hence large spans are desirable, and the suspension form has been adopted as meeting this in the most economical way.

Length of bridge, headway, width of roadway.—The total length of waterway provided is 500 feet. This bridges the whole stream, and is, I think, precisely suitable. The headway above the highest known flood-level is to the bottom of the stiffening girder, and is not a straight line, but rises in the centre of the span to 10·0 feet, and may be accepted as adequate. The width of roadway is 14 feet inside the railings. This is sufficient for a single line of carts, and fully meets the requirements of the traffic which this bridge will have to carry.

Load the bridge is capable of carrying.—The iron-work has been given dimensions to fit it to support a dense crowd of men or a continuous string of laden hackeries.

Depth of foundations.—We have no knowledge of the depth to which the bed may be scoured or moved during heavy floods. On this point we cannot expect any evidence until the excavation of the pits for the foundations has made good progress. The design and estimate provide for foundations placed at 30 feet below low-water level, or 25 feet below the lowest part of the bed. This is a very full allowance, and probably in excess of what will be found to be required.

Plan of the crossing mislaid.—The plan of the crossing has been mislaid, but this is not of much importance, as there is no peculiarity in the approaches, which moreover form part of the estimate for the road, and not of that for the bridge.

Project very carefully prepared.—The project has been most carefully prepared by Major J. Browne, R.E.

Estimated cost.—The estimated cost of the work is Rs. 3,05,453. The length of the road is 610 feet from out to out. The cost per foot is therefore $\frac{315,453}{610}$ = Rs. 500·74. If rated on the waterway only, the cost per foot run would be $\frac{305,453}{510}$ = Rs. 598·92.

(Sd.) A. T.

Free Extracts from Report and Estimate by Major Browne.

The bridge has one centre span of 250 feet clear, and two side bays of 130 each. The versed sine of the curve of the chain is 26 feet.

The greatest depth of water at highest flood is 12 feet, and the headway is 8 feet above H. W. M. at piers, and 10 feet in centre of river.

The piers and abutments are founded on solid masses of concrete 10 feet thick, laid in excavations 25 feet below lowest point of bed. The concrete was laid in a sort of cofferdam of brickwork, which allowed of its being thoroughly well rammed about the edges.

The mass of masonry in the abutments is somewhat less than usual, an attempt having been made to economize masonry by the peculiar disposition of the anchorage chains.

The one main and solid objection to the use of suspension bridges even for cart traffic, being their need of constant repair from the wear and tear of the component parts due to the undulations set up by rolling loads, but more especially by the action of the wind, great attention has been paid to reducing these undulations to a minimum.

The action of the wind is resisted and neutralized—

(1). By the chains themselves.

(2). By the peculiar arrangement of the suspension rods.

(3). By the bracing in the floor and the great depth and stiffness of the cross and longitudinal girders.

The main chains being on a tilt of 1 in 7 and very much further apart at the piers (where they are kept apart by wrought-iron standards) than at the centre and abutments, add greatly to the stability of the bridge against the action of the wind. The theory of the advantage of such an arrangement of the chains is, that a vertically hanging chain, however heavy, can only resist the action of the wind to sway it, by means of the friction developed in the top pins on which it swings; whereas a chain already tilted up, resists all tendency to swing, not only with friction, but with the whole leverage of its own weight, into an arm varying with the angle of tilt. That this resistance or leverage is very considerable will be seen by a reference to the calculations, on which however no great stress has been laid, as the system has got the far greater advantage of having been practically tried in many large works, and found to yield excellent results. The whole of the large modern American bridges, at Cincinati (1100 feet span), Niagara (880 feet) and the East River (1600 feet) have been built on this system, with the most satisfactory result as to immunity from the action of the wind and general stability. The Albert bridge over the Thames, lately completed and probably the best type of suspension bridge now in Europe, is also built with slanting chains, and is almost as stiff in a gale of wind as a stone bridge, the result being ascribed by its Engineer, Mr. Ordish, to the disposition of the chains. As the cost of the Jamna bridge is not to any serious extent increased by this plan, no hesitation has been felt in adopting it.

To prevent as far as possible any swaying in the chains being communicated to the platform or *vice versâ*, the suspension rods are double jointed and capable of free motion, either in the direction of the length of the bridge or perpendicular to it. This arrangement is that adopted in the great Suspension Bridge over the Moldau at Prague, and effectually prevents periodicity, or isochronous oscillations of the chain and platform, and tends in other ways greatly to increase general stability.

The bracing in the floor forms a continuous girder over the whole length of the piers and abutments, being strengthened at those points with plate webs and double diagonals.

The continuity over the piers and the fixing at the abutments are obtained by a system of sliding collars and castings, which, while allowing free expansion and contraction of the girder in a longitudinal direction, prevents all lateral motion, and will, it is hoped, give very great stiffness to the platform, irrespective of its being of iron throughout, and rivetted up, in one piece, from end to end of the bridge. The sliding collars will further prevent any kind of lateral pressure upon the stiffening girder, having a tendency to bend the rocker bars, and thus endanger them. The great depth (20 inches and 15 inches) of the main and longitudinal roadway girders, would in themselves go far to secure, what is admitted to be most essential, a deep and stiff floor; the stability being further increased by the solid manner in which the floor baulks and planking are connected to the girders.

The action of rolling loads is counteracted by deep and stiff girders, which are continuous from end to end of the bridge; and which further, with the wheelguard, serve the purposes of parapets.

As the first essential in a stiffening girder is that it should be incapable of vertical motion at the ends, this end is attained by the use of large cast-iron rockers, on the piers and abutments, which prevent all upward movement, whilst giving perfect freedom to the girders for horizontal contraction and expansion. The rockers are fixed down to the masonry by wrought-iron bars, which are fixed when heated, and then allowed to cool and contract, thus bringing an initial strain on the bar, and preventing all upward motion of the girder and platform, which are however free to move horizontally on what are really eight large wheels six feet in diameter. All risk of strain to the girder, from rise or fall of temperature, is thereby avoided, and permits of sliding joints being dispensed with, which have hitherto been found necessary in such stiffening girders to suspension bridges; but which, to a great extent, do away with the advantages of a stiffening girder, besides being troublesome in construction and needing constant repair.

As however sudden changes of temperature must always produce unequal strains in an iron structure of such length, a certain amount of flexibility has been given to the girder by pinning instead of rigidly rivetting its diagonals, thus allowing of a certain amount of angular motion in each panel. This plan has been adopted with excellent effect in the great Suspension Bridge at Cincinati (1100 feet span). The position of the diagonals of the girder is to a certain extent incorrect in theory, as not intersecting in the neutral axis of the boom; but the additional stress resulting from this has been provided for by strengthening plates near the pins, and had to be adopted from practical considerations.

The construction of the main chains is in no way unusual beyond the tilt given to them, and their arrangement in a quadrantal shape in the abutment tunnel. The first has been already remarked on, and the second, although perhaps rather unusual in Europe, is that universally adopted throughout America. It has, besides saving in the length of back chain, the advantage of lessening very considerably the strain on the iron in those very parts of the chain which are most likely to be overlooked and neglected, *viz.*, the ends of the tunnels; as it is estimated that the friction on the knuckles, &c., takes off fully one-third of the strain from the lower chain link. The section of iron has not been diminished on this account, friction not having been taken into consideration in the calculations; but it is nevertheless an important advantage.

The building in of the last link in the main chain and enveloping it in Portland cement, is somewhat unusual in Europe, but is the general American practice, where the whole of the back chains, and not merely the last link, are systematically built in as in the Niagara, East River, and Cincinati bridges. It has been urged, from the fact of iron cramps in masonry being found to decay quickly, that such a mode of coating the chain, or building it in, might prove detrimental; the fact really being that the decay of built in iron cramps, is due to the galvanic action set up between the iron and the lead with which the cramps are fixed; whereas such galvanic action and corrosion is especially guarded against in the holds of all ironclad ships and steamers by coating with thick layers of Portland cement, which adheres firmly to the iron. In such a damp and inaccessible position, below water level, as the last link on the anchorage necessarily occupies, it is thought better to trust for the protection of the iron, once for all, to a solid envelope of good Portland cement quite impermeable to water, and carefully rammed and filled in round the chain, during construction, than to a coat of possibly indifferent paint, applied at long intervals of time, without in all probability the iron having been properly scraped and cleaned for its reception.

None of the parts of the ironwork are so heavy or large as to produce any difficulty in transport; the heaviest casting being $1\frac{3}{4}$ *tons* in weight, these being the anchor plates, of which there are only four; none of the other castings weighing one-half as much. The heaviest single part of wrought-iron will be a main roadway girder weighing 464 lbs. It will of course be left to the discretion of the manufacturer at home to do as much of the rivetting and permanent putting together as can possibly be done without involving extra freight, or risk of injury to the ironwork.

The site of the bridge being very favourable for the construction of scaffoldings, and the natural surface not being at more than an average depth of 18 or 20 feet below the lower edge of the stiffening girder, the fitting and erection of the girder will not be a matter of any difficulty or great expense. As to the chains, by commencing at the tops of the piers, with one single and two half links on either side, and dragging them across, on little trollies fitting between the channel irons on the top boom of the girder, the weights will be so subdivided as to be quite within the control of mere manual labour; and much more so with a 4 or 5 ton winch and tackle. Such details will however be best suggested by the Engineer on the spot, and are only mentioned to show that there seem, after much consideration, no serious difficulties in the way of erection. It may however not be out of place to mention that the chains when put up must be *as short* as the adjusting links can make them; as it is intended that all adjustments shall be made by *lengthening* and not *shortening* the chains; the former being much the easier process, and the wedges and links having been so arranged that there can never be any need to make the chain *shorter* than it will be when all the wedges are inserted. Another necessary caution will be that the position of the saddles, rollers, bed plates and sliding collars, must be adjusted with proper reference to the difference of temperature at the time of fixing, and that assumed as the normal temperature 80° Fah.

As to estimated cost of bridge, the rates are those obtained from the local officers, and in some cases, as in that of the concrete, considerably raised. The only reduction is in the price of castings, which are placed at £5 a ton less than wrought-iron. The latest quotation from the *Iron Trade Review* gives the prices as below—

	£.		£.	
Wrought-Iron Girders... ...	20	to	21	a ton,
Girder casting, ...	10	,,	11	a ton,

or an average difference of £10 a ton in cost price; so that £5 a ton is quite a fair and allowable difference in rate.

The cost of the bridge per running foot of waterway (say Rs. 450) cannot be considered high. The exceedingly costly nature of the foundations, and the great depth to be reached; the fact that the main roadway is entirely of iron, the very heavy rolling load to be provided for, and the great rigidity aimed at, which, if attained to, will be quite equal to that of any ordinary railway bridge of the same span, have all tended to swell the cost. Much might have been saved by lowering the standard in one or in all of the above requirements, but the result would not, in the long run, be so satisfactory, either as to cost or construction, as it is hoped the proposed bridge may prove hereafter to be.

Note on the Adjustment of the Rockers and Rocker Bars.

In the calculations for the bridge it is shown that the rocker should originally be placed at an angle of about 11°; and as the bar gets heated it would expand sufficiently to allow the rocker to stand vertically on being gently driven with a mallet; after which on the cooling of the bar, there would be an initial strain of about 2 tons per square inch on the metal. This will however be better understood from *Fig.* 1, *Plate* II., in which A shows the original, and B the ultimate position of the rocker, which is driven in the direction of the arrow, as the bar is heated, expands ·62 of an inch; which increase of length is retained as the bar cools, causing the requisite initial strain of 10 tons, holding down the girder. To allow for the compression of the masonry, the angle of tilt can probably be made 13° or 14° instead of 11°, which would be the proper angle, were the masonry quite incompressible.

The vertical slit in the masonry, left round the rocker bar, shall be 15 inches long by 4 inches wide; an open gutter hole 6" × 6" being built in the masonry from below the lower rocker casting, to carry off the water, and to allow of fresh boiling water being poured in if required. The end of this gutter hole, at the face of the pier or abutment, to be closed by a piece of stone into which a jumper hole 2 inches in diameter is made, into which a plug can be inserted to regulate the flow of the water, and let it off as it cools, to allow more hot to be poured in. The inside of the slit and gutter to be well plastered to keep in the heat. The arrangement will be sufficiently clear from *Fig.*, 2, *Plate* II., showing a rocker and bar at a pier.

The quantity of boiling water needed to fill the slit will not exceed 75 gallons. The arrangement at an abutment is similar to that at a pier. When the rocker has been properly fixed, the slit and gutter to be filled up with thick grouting or mortar.

Abstract of Cost.

Quantity.	Description	Rate	Cost			Remarks
Tons.		RS.	RS	A.	P.	
211·5	Wrought-iron, ...	560	1,18,440	0	0	Per ton.
25·4	Cast-iron, ...	500	12,700	0	0	„
c. ft. 2,702	Deodar wood, ...	3	8,106	0	0	Per c. ft.
86,154	Concrete, ...	15	12,923	0	0	Per 100 c. ft.
2,02,782	Coursed masonry, ...	35	70,974	0	0	„
6,066	1st class ashlar, ...	4	24,264	0	0	Per c. ft.
6,150	2nd class ashlar,..	2	12,300	0	0	„
17,718	Brick masonry, ...	35	6,201	0	0	Per 100 c. ft.
	Pumping and excavation, ..		25,000	0	0	Lump sum.
	Total of above, ...		2,90,908	0	0	
	Contingencies, ...	5	14,545	0	0	
	Grand Total cost, Rs., ..		3,05,453	0	0	

It will be observed that no detailed dimensions are given in the plans. None are given in the original plans, they are all contained in the volume of calculations, and there is not time to extract them in detail. The "book of measurements" was probably sent home to the contractors who supplied the iron. The data for calculation were as follows:—The ultimate tenacity of the suspension chains was taken at 30 tons with factors of safety of 6 for live, and 3 for dead, load. In the rest of the bridge the ultimate tenacity of the iron was taken at 25 tons, and the safe stress in tension and compression at 5 and 4 tons.

The rolling load was taken as that of a crowd weighing 120 lbs. per square foot. In concentrated loads it was assumed that the greatest possible weight on one axle was 3 tons, which is about equivalent to the weight of a loaded elephant. The force of the wind was taken at 40 lbs. per foot, *Extract from Report of Superintending Engineer, Colonel Perkins, R.E., on completion of Bridge.*

The excavation for the bridge was commenced in December 1875, the masonry in April 1876, the ironwork in January 1878, and the bridge was opened for traffic in June 1878. The work has been carried through without accident and only one hitch. This was due to an alteration in the sanctioned design which was made by the iron manufacturers in England, and is as follows:—

In consequence of the chains of this bridge being curved outwards in plan from the lower to the upper points of the catenaries, the suspension rods are not vertical, as they would have been had the chains been straight in plan. Consequently the suspension brackets were so designed by Major Browne that whilst the pin hole at head might receive the usual connecting pin of the links of the chain, the pin hole at bottom was by a twist in the shank of the bracket to assume a contrary position so as to receive a pin lying parallel to the line of bridge, see *Figs.* 1 and 2, *Plate* III. From misappreciation of the design possibly, the brackets were sent out as if for chains without this curve in plan, *i.e.*, as shown by sketches, *Figs.* 3 and 4, *Plate* III., and consequently some little apprehension was occasioned on account of the suspension bar B, *Fig.* 3, having to be bent at B to allow of it assuming the position shown, and this more especially in the lower and shorter bars, where the angular deflection is greater. The result of the trial however shows that there need be no further apprehension on this point, although the effect is somewhat unsightly.

The Executive Engineer, Major H. Blair, R.E., reports as follows:—

I have the honour to submit Mr. Birkbeck's plans and report on the testing of the Jamna bridge, which according to orders received, had to be tested to 120 lbs. per square foot, or 320 tons.

We commenced on the 12th June, by putting half the load evenly over the whole bridge, beginning at the piers, working both ways, and as I had only doubts about the suspension bars, I thought I would weight the side spans fully first, which would test them to their full extent, at the same time show how the bridge acts under an uneven load.

By noon the side spans were fully weighted, and about 60 lbs. per square foot on the centre span, and the work closed until 6 p.m. From the weight, extreme heat and uneven load, the girder looked so strained at points and began contracting in jerks, that I nearly stopped the test at 8 p.m. After a long consultation we resumed work, and put the full load on, noted deflection, and after two hours removed the weight.

Next morning we took levels and examined the bridge, and I have great pleasure in reporting that nothing has failed. This bridge has been successfully completed without any loss of life, and tested by the same officers from first to last (a very remarkable event in the Public Works Department). A little cornice work remains, and although the bridge has been raised 5 feet in height, I hope to complete it well within the sanction, without submitting a revised estimate.

Mr. Birkbeck's Report.

Orders were given by the Chief Engineer, Military Works, to test the bridge with a dead load of 120 lbs. on each superficial foot of roadway, the bridge was accordingly tested on the 12th instant.

To effect this the bridge was loaded with a weight of 298·6 tons distributed as follows:—149·3 tons on the centre span, 74·65 tons on each of the side spans, this together with the weight of the workpeople employed loading amounts very nearly to the weight required.

The material used for loading was gravel from the bed of the river, spread 11 inches deep over the width of the roadway, and confined at the sides with an edging of bricks.

The load was put on each end of the bridge, the beldars spreading the gravel from each pier outwards to the centre of the bridge, and inwards to the abutments.

To measure the amount of deflection under the load, fourteen self-recording gauges were set up, seven under each boom of the stiffening girder. Before loading also levels were taken at intervals of every 20 feet, and when the load was taken off, the levels were again taken to measure the amount of permanent set, these levels and measurements are all shown in the deflection diagrams submitted.

To insure as much as possible correct measurements, the levels were taken at the same time of day when the temperature is the same, this is a very necessary precaution, as the bridge chains and girders sometimes rise and fall ·24 of a foot or three inches within 12 hours with the expansion alone. The levels were therefore taken on the morning of the

12th before the load was on, and again on the morning of the 13th when the load had been taken off.

The chains were also levelled before and after loading, but as no permanent deflection was shown, no diagrams have been submitted.

The movement of the saddles on the top of the piers was also observed, the abutment saddles were noticed, but there was no movement observed in them.

The following movements were observed in the bridge at the time of loading :—On the loading of the side spans, which was finished before the centre span, the girder in the side span deflected 4¾ inches under uneven loading, when the complete load was on the centre span the side girders rose again one inch, *i. e.*, showed a deflection of 3¾ inches only, at the same time the pier saddles advanced ⅝-inch each towards the abutments, but resumed their original positions when the full load was on the centre span. Another movement observed was that the diagonal braces of the stiffening girder were affected by the weight, those in compression buckling, and those in tension getting very tight and strained, the suspension rods also were evidently very taut under the load, but when it was taken off they resumed their normal condition and could be shaken by hand.

After the testing, two of the Commissariat elephants have crossed the bridge at the same time, not the slightest movement or deflection was observed whilst they were crossing.

The general result of the test may be summed up as follows—1*st*, that under the load imposed the centre span showed a maximum deflection at the centre of 2⅞-inch, and that the spans under the same conditions showed a deflection of 3¾ inches; 2*nd*, that the bridge has nearly resumed its original form, after unloading the maximum permanent set in one girder being 0·13 and in the other 0·16; 3*rd*, the bridge chains, pier and abutment saddles are the same, there being no alteration in their positions.

Up-stream Girder.

Point on diagram.	Reading of Gauges.			Deflection under load	Permanent set.	Remarks
	Before loading	With load on	After removal of load.			
	Side span, north side.					
A	0·00	0·34	0·07	0·34	0·07	At 40 feet from north abutment.
B	0·00	0·35	0·03	0·35	0·03	At 90 feet from north abutment, due to uneven load, side spans being weighted first.
	Centre span, up-stream girder.					
C	0·00	0·14	0·08	0·14	0·08	At 50 feet from north pier.
D	0·00	0·24	0·12	0·24	0·12	At centre of bridge.
E	0 00	0·20	0·02	0·20	0·02	At 50 feet from south pier.
	Side span south side, up-stream girder.					
F	0·00	0·32	0 03	0·32	0·03	At 90 feet from south abutment.
G	0·00	0·27	0·06	0·27	0·06	At 40 feet from south abutment.

(Gauges set at these points, intermediates taken by a level rather late in the evening.)

Down-stream Gauges.

Point on diagram.	Before loading	With load on	After removal of load.	Deflection under load	Permanent set.	Remarks
	Side span, north side.					
A'	0·00	0·32	0·03	0·32	0·03	At 40 feet from north abutment.
B'	0·00	0·34	0·09	0·34	0·09	At 90 feet from north abutment.
	Centre span, down-stream girder.					
C'	0·00	0·20	0·09	0·20	0·09	At 50 feet from north pier.
D'	0·00	0·24	0·16	0·24	0·16	At centre of bridge.
E'	0·00	0·17	0·04	0·17	0·04	At 50 feet from south pier.
	Side span south side, down-stream girder.					
F'	0·00	0·37	0·07	0·37	0·07	At 90 feet from south abutment.
G'	0·00	0·27	0·03	0·27	0·03	At 40 feet from south abutment.

***N.B.*—The indicators of the gauges were set at zero before loading.**

PLATE II

JAMNA RIVER SUSPENSION BRIDGE.

Figures from hand sketches.

Fig. 1.
AS DESIGNED

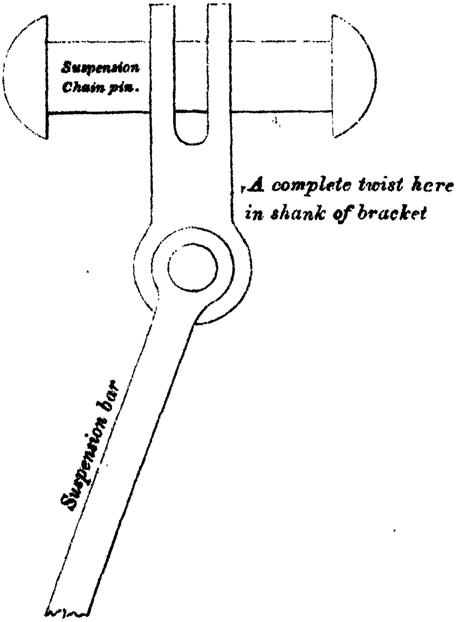


Fig. 3.
AS CONSTRUCTED

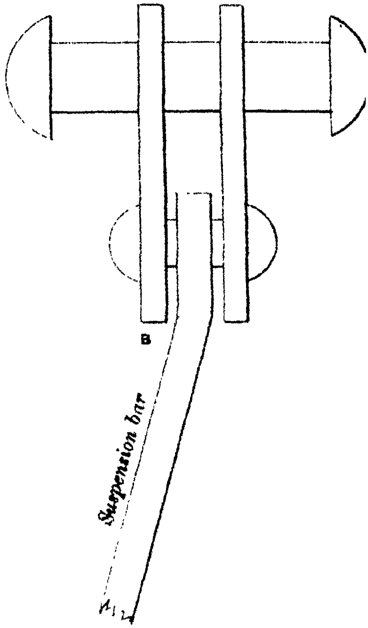


Fig. 2.

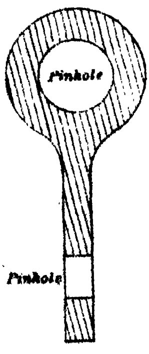
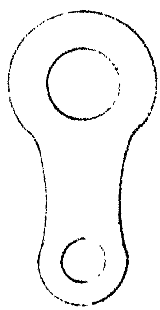


Fig. 4.



No. CCCII.

REPORT ON EXPERIMENTS MADE AT LUCKNOW ON STRENGTH OF SAL AND TEAK TIMBER, IN 1877 AND 1878.

By Capt. J. Dundas, V.C., R.E., *Assistant to Inspector General, Military Works.*

Experiments made in the Panjab having shown that the recorded constant coefficients ordinarily used in calculations of the transverse strength and stiffness of deodar timber were too large* to give correct results in the case of seasoned beams of some size, the question was raised whether the constants commonly used for sal and teak timber might not be found on trial to be equally untrue.

Instructions were accordingly given for a series of experiments to be made at Lucknow, under the conditions stated below.

(*a*). On 12 pieces of seasoned sal wood; each piece 12 feet long and 6″ × 4″ scantling.

(*b*). On 12 pieces of seasoned teak wood; of the same dimensions.

(*c*). On 12 pieces of seasoned sal wood; each piece 30 inches long and 1 inch square.

(*d*). On 12 pieces of seasoned teak; of the same dimensions.

The distance between the supports to be 10 feet in the case of the larger scantlings, and 2 feet in the case of the smaller ones.

The load to be applied at the centre. About $\frac{1}{20}$ of the calculated breaking weight to be first applied and to be left on for 7 days. The deflection at the centre to be then carefully measured in inches and decimals.

* The experiments showed—
E_d = 1,800, instead of the usual 3,500.
P^b = 300, " " " 500.

The load to be afterwards doubled, and at the end of 7 days more the deflection to be again measured.

The load at the centre to be next increased to $\frac{3}{20}$ of the breaking weight, and after 7 days the deflection to be again measured.

After this, the load to be gradually increased till fracture takes place. The breaking weight to be noted, and the maximum deflection obtained if possible.

These orders have been faithfully carried out. The timber used in the experiments, especially the teak wood, was of above the average quality that would be used in work in India; but it was not especially selected for the experiments, as there happened to be a large quantity of good timber in stock. The sal beams were cut from large sound logs, which, from their appearance, must have been well seasoned. The teak beams were sawn from Moulmein logs of a very large size, varying from 50 to 100 cubic feet each, of a very superior quality, and fairly seasoned. After sawing, the beams were planed down to their true dimensions, and they were all carefully examined to see that they were free from shakes or large knots. In the smaller specimens there were no knots at all.

The sal wood was found to weigh 59 lbs. per cubic foot, and the teak wood 34 lbs. per cubic foot. In respect to this last figure, which is much smaller than the weight assigned to teak wood in the various text-books in common use, the Executive Engineer observes that teak wood received in large logs contains a great deal of moisture, presumably on account of the logs having been for a long time lying in water. Its weight, as received in the log at Lucknow, remains for a long time at very nearly 50 lbs. per cubic foot; but as soon as it is sawn up into planks or scantlings, it begins to dry, and the weight in a very short time comes down to about 34 or 35 lbs. per cubic foot, at which it appears to remain.

The following particulars as to the method of conducting the experiments will be of interest:—

"The supports for the large beams consisted of brick walls built in Portland cement, with good foundations of lime concrete. The beams were placed on heavy flat bars of iron, resting on the tops of the walls, which were accurately levelled, and the distance between bearings gauged. There was no possibility of any shifting of the bearings."

The weights used were pieces of iron, and they rested on two pairs of railway wagon wheels and axles, which were suspended by wire rope from a shackle of $4\frac{1}{2}'' \times \frac{1}{2}''$ bar-iron resting on the middle of the beam, and having a bearing on it $4\frac{1}{2}$ inches wide.

"When the beam was in position, ready for weighting, a line, wetted with red colouring matter, was stretched tight between the two points where the lower surface of the beam on one side of it intersected the inner side of its bearings on the same side. The line was then stretched at the centre and allowed to spring back sharply, the result being a horizontal red line on the shackle."

In order to measure the deflection resulting from the several loads applied, the process with the line was repeated; the distance between the red lines on the shackle was measured with a divided scale.

The experiments on the small beams were similarly conducted. The supports used were "the axles of railway wagon wheels, which were carefully levelled, and the distance between bearings measured." The shackle used was only $1\frac{1}{2}'' \times \frac{1}{2}''$, and had a bearing $1\frac{1}{2}$ inches broad.

So far as the experiments on the larger beams are concerned, the possible sources of error in observation seem to be the following:—

I. The beams were not supported at the middle up to the time when the first red mark was made upon the shackle, and no account was taken of the deflection (if there was any) due to the weight of the beam itself. On this point the Executive Engineer says—

"The weight of the beam was so small, compared with their strength, that they would warp before they deflected with their own weight; the beams were however, as nearly as practicable, horizontal when the first red line was marked, as was seen by the cord as a rule marking the arris of the beam."

II. "Owing to the thickness of the red lines, the deflections should only be considered accurate within from $\frac{1}{16}''$ to $\frac{1}{20}''$."

In the case of the smaller specimens, besides the two sources of possible error above noted, there was a risk of settlement of the bearings. The Executive Engineer observes—

"If there was any settlement in this latter case, it must have been insignificant, as the wheels were well chocked up, and the ground on which they rested hard. The weights, too, were trifling."

On the whole, it seems that though the observations may not have been free from small errors, the genenal results drawn from them may be accepted as trustworthy. Details of the observations will be found in the tables marked I. to IV., which are annexed to this paper. Table V. shows the proportion borne by the first, second, and third loads in each set of experiments to the breaking weight under which failure took place.

Table VI. shows the value of P_b resulting from the experiments on transverse strength of each class of timber; and Table VII. gives similar information in respect to the coefficient for stiffness E_d. Lastly, Table VIII. shows the values of these coefficients which have hitherto been made use of in calculation, with the authorities from which they are taken.

From a consideration of these tables, it will be seen that the values hitherto assigned to P_b and E_d for sal and teak, though possibly correct for such small specimens as those on which the original experiments were made, cannot be accepted as truly representing the strength or stiffness of larger scantlings. The present experiments seem to justify the adoption for future use of the following coefficients:—

		Sal.	Teak.
For transverse strength	P_b	550	470
For stiffness	E_d	2,500	2,200

It may at first sight appear as though the adoption of the figures here proposed would lead to the use of much heavier and more expensive timbering in roofs than has hitherto been thought proper. But this will not be found to be the case if the loads which the beams will have to bear are carefully considered. For a permanent load, a factor of safety of 10 for transverse strength, and a maximum deflection of $\frac{1}{40}$ of an inch per foot of span are to be required, as has usually been done. But for a maximum load, of which a great part is not constant but only of a temporary kind, a factor of safety of 6 and a maximum deflection of $\frac{1}{20}$ of an inch per foot of span may be allowed. As an illustration, it may be mentioned that in the type drawings of half-company's barracks for British Infantry now about to issue, the deflection allowed in the rafters is about $\frac{1}{38}$ to $\frac{1}{41}$ of an inch per foot of span under the permanent load, and rises to from $\frac{1}{22}$ to $\frac{1}{20}$ under the additional temporary load of a violent wind.

Table I.

CLASS A.—Report of Experiments made in the manner directed in Inspector-General's letter No. 3664, dated 11th June 1877, to ascertain the value of E_d *for seasoned Sal in the ordinary deflection formula* $BD^3 = \frac{L^3W}{E_d}$ *when*

$L = 10$ *feet*, $D = 6$ *inches, and* $B = 4$ *inches.*

Specimen.				Weight in pounds applied at centre, and resulting deflections at end of seven days.						Weight at centre that produced fracture and final deflection.	
				1st load about 1/20 of breaking weight		2nd load about 2/20 of breaking weight.		3rd load about 3/20 of breaking weight.		Final load.	
No. of Beams.	Dimensions.	Distance between supports.	Weight of a cubic foot.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured as nearly as possible before fracture.
		Feet.	lbs.	lbs.		lbs.		lbs.		lbs.	
1 Sal	12′ × 6″ × 4″	10	59	553	0·25	1,106	0·75	1,659	0·87	9,520	4·00
2 "	12′ × 6″ × 4″	10	59	553	0·25	1,106	0·50	1,659	0·75	9,913	3·50
3 "	12′ × 6″ × 4″	10	59	553	0·00	1,106	0·25	1,659	0·62	9,963	2·18
4 "	12′ × 6″ × 4″	10	59	553	0·18	1,106	0·50	1,659	0·75	7,213	6·00
5 "	12′ × 6″ × 4″	10	59	553	0·25	1,106	0·43	1,659	1·00	5,332	Not obtained.
6 "	12′ × 6″ × 4″	10	59	553	0·12	1,106	0·43	1.659	0·43	8,351	2·55
7 "	12′ × 6″ × 4″	10	59	553	0·43	1,106	0·50	1,659	0·70	7,188	2·12
8 "	12′ × 6″ × 4″	10	59	553	0·43	1,106	0·75	1,659	0·93	6,846	2·62
9 "	12′ × 6″ × 4″	10	59	553	0·43	1,106	0·74	1,659	1·00	8,020	1·55
10 "	12′ × 6″ × 4″	10	59	553	0·62	1,106	0·75	1,659	0·81	6,660	Not obtained.
11 "	12′ × 6″ × 4″	10	59	553	0·37	1,106	0·62	1,659	0·93	7,198	3·50
12 "	12′ × 6″ × 4″	10	59	553	0·55	1,106	0·75	1,659	1·00	8,447	3·56

For Values of P_b and E_d deduced, *see* Tables VI. and VII.

Table II.

CLASS B.—Report of Experiments made in the manner directed in Inspector-General's letter No. 3664, dated 11th June 1877, to ascertain the value of E_d *for seasoned Teak in the ordinary deflection formula* $BD^3 = \frac{L^3W}{E_d}$, *when*

$L = 10$ *feet*, $D = 6$ *inches, and* $B = 4$ *inches.*

Specimen.				Weight in pounds applied at centre, and resulting deflections at end of seven days.						Weight at centre that produced fracture and final deflection.	
				1st load about $\frac{1}{20}$ of breaking weight.		2nd load about $\frac{2}{20}$ of breaking weight.		3rd load about $\frac{3}{20}$ of breaking weight.		Final load.	
No. of Beams.	Dimensions.	Distance between supports.	Weight of a cubic foot.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured as nearly as possible before fracture.
		Feet.	lbs.	lbs.		lbs.		lbs.		lbs.	
1 Teak	12′ × 6″ × 4″	10	34	492	0·25	984	0·50	1,386	0·75	7,964	3·18
2 "	12′ × 6″ × 4″	10	34	492	0·00	984	0·25	1,386	0·50	8,564	3·06
3 "	12′ × 6″ × 4″	10	34	492	0·00	984	0·75	1,386	1·06	4,218	Not obtained.
4 "	12′ × 6″ × 4″	10	34	492	0·18	984	0·50	1,386	0·75	5,932	Not obtained.
5 "	12′ × 6″ × 4″	10	34	492	0·18	984	0·43	1,386	0·50	8,514	2·18
6 "	12′ × 6″ × 4″	10	34	492	0·43	984	0·50	1,386	0·80	8,542	2·12
7 "	12′ × 6″ × 4″	10	34	492	0·43	984	0·74	1,386	1·00	4,610	1·55
8 "	12′ × 6″ × 4″	10	34	492	0·00	984	0·49	1,386	0·68	7,210	2·12
9 "	12′ × 6″ × 4″	10	34	492	0·12	984	0·43	1,386	0·86	5,537	1·80
10 "	12′ × 6″ × 4″	10	34	492	0·75	984	1·00	1,386	1·50	8,440	2·00
11 "	12′ × 6″ × 4″	10	34	492	0·75	984	1·00	1,386	1·25	4,140	Not obtained.
12 "	12′ × 6″ × 4″	10	34	492	0·37	984	0·55	1,386	0·87	6,709	2·62

For Values of P_b and E_d deduced, *see* Tables VI. and VII.

TABLE III.

CLASS C.—Report of Experiments made in the manner directed in Inspector-General's letter No. 3664, dated 11th June 1877, to ascertain the value of E_d *for seasoned Sal in the ordinary deflection formula* $BD^3 = \frac{L^3W}{E_d}$, *when* $L = 2$ *feet,* $D = 1$ *inch, and* $B = 1$ *inch.*

SPECIMEN.				WEIGHT IN POUNDS APPLIED AT CENTRE, AND RESULTING DEFLECTIONS AT END OF SEVEN DAYS.						WEIGHT AT CENTRE THAT PRODUCED FRACTURE AND FINAL DEFLECTION.	
				1ST LOAD ABOUT $\frac{1}{20}$ OF BREAKING WEIGHT.		2ND LOAD ABOUT $\frac{2}{20}$ OF BREAKING WEIGHT.		3RD LOAD ABOUT $\frac{3}{20}$ OF BREAKING WEIGHT.		FINAL LOAD.	
No. of Beams.	Dimensions.	Distance between supports.	Weight of a cubic foot.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured as nearly as possible before fracture.
		Feet.	lbs.	lbs.		lbs.		lbs.		lbs.	
1 Sal	30″ × 1″ × 1″	2	59	19	0·06	38	0·12	76	0·25	418	2·00
2 ,,	30″ × 1″ × 1″	2	59	19	0·06	38	0·06	76	0·25	432	1·25
3 ,,	30″ × 1″ × 1″	2	59	19	0·00	38	0·06	76	0·12	458	1·00
4 ,,	30″ × 1″ × 1″	2	59	19	0·06	38	0·12	76	0·25	327	1·75
5 ,,	30″ × 1″ × 1″	2	59	19	0·06	38	0·12	76	0·25	392	1·25
6 ,,	30″ × 1″ × 1″	2	59	19	0·06	38	0·06	76	0·18	354	1·50
7 ,,	30″ × 1″ × 1″	2	59	19	0·00	38	0·06	76	0·18	398	1·00
8 ,,	30″ × 1″ × 1″	2	59	19	0·00	38	0·06	76	0·12	503	1·50
9 ,,	30″ × 1″ × 1″	2	59	19	0·06	38	0·12	76	0·18	507	1·75
10 ,,	30″ × 1″ × 1″	2	59	19	0·06	38	0·12	76	0·12	498	1·25
11 ,,	30″ × 1″ × 1″	2	59	19	0·06	38	0·18	76	0·25	509	1·50
12 ,,	30″ × 1″ × 1″	2	59	19	0·12	38	0·18	76	0·18	375	1·25
		Mean of 12 experiments.			0·05	...	0·11	...	0·19	431	1·42
		Maximum ,,			0·12	...	0·18	...	0·25	509	2·00
		Minimum ,,			0·00	...	0·06	...	0·12	327	1·00

For Values of P_b and E_d deduced, *see* Tables VI. and VII.

TABLE IV.

CLASS D.—Report of Experiments made in the manner directed in Inspector-General's letter No. 3664, dated 11th June 1877, to ascertain the value of E_d for seasoned Teak in the ordinary deflection formula $BD^3 = \frac{L^3W}{E_d}$, ***when*** $L = 2$ *feet*, $D = 1$ *inch, and* $B = 1$ *inch.*

SPECIMEN.				WEIGHT IN POUNDS APPLIED AT CENTRE, AND RESULTING DEFLECTIONS AT END OF SEVEN DAYS.						WEIGHT AT CENTRE THAT PRODUCED FRACTURE AND FINAL DEFLECTION.	
				1ST LOAD ABOUT $\frac{1}{25}$ OF BREAKING WEIGHT.		2ND LOAD ABOUT $\frac{2}{25}$ OF BREAKING WEIGHT.		3RD LOAD ABOUT $\frac{3}{25}$ OF BREAKING WEIGHT.		FINAL LOAD.	
No. of Beams.	Dimensions.	Distance between supports.	Weight of a cubic foot.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days.	Load in lbs.	Deflection in inches and decimals measured after the load had been applied seven days	Load in lbs.	Deflection in inches and decimals measured as nearly as possible before fracture.
		Feet.	lbs.	lbs.		lbs.		lbs.		lbs.	
1 Teak	30″ × 1″ × 1″	2	34	17	0·06	34	0·12	51	0·25	448	1·25
2 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·06	51	0·12	321	1·50
3 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·12	51	0·25	401	1·00
4 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·18	51	0·25	394	1·50
5 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·12	51	0·25	465	1·12
6 „	30″ × 1″ × 1″	2	34	17	0·12	34	0·12	51	0·18	442	1·06
7 „	30″ × 1″ × 1″	2	34	17	0·00	34	0·12	51	0·18	301	1·25
8 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·12	51	0·25	401	1·25
9 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·12	51	0·25	475	1·25
10 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·18	51	0·18	305	1·00
11 „	30″ × 1″ × 1″	2	34	17	0·06	34	0·12	51	0·18	475	1·75
12 „	30″ × 1″ × 1″	2	34	17	0·00	34	0·18	51	0·18	309	1·25
		Mean of 12 experiments.			0·06	...	0·13	...	0·21	395	
		Maximum		„	0·12	...	0·18	...	0·25	475	
		Minimum		„	0·00	...	0·06	...	0·12	301	

For Values of P_b and E_d deduced, *see* Tables VI. and VII.

Table V.

Showing the proportion borne by the 1st, 2nd, and 3rd loads in each set of experiments, to the breaking weight under which failure took place.

Loads in what case.	Proportion of breaking weight.		
	1st Load.	2nd Load.	3rd Load.
As ordered, ...	·05	·10	·15
Actual load in Experiment A, ..	·06 to ·10	·12 to ·20	·17 to ·31
" " B, ..	·06 to ·12	·12 to ·24	·16 to ·34
" " C, ..	·04 to ·06	·07 to ·12	·15 to ·28
" " D, ..	·04 to ·06	·07 to ·12	·11 to ·17

Table VI.

Showing the value of P_b *resulting from the breaking loads stated by the Executive Engineer, if half of the weight of the unsupported length of the beams themselves be added thereto.*

Distinguishing letter of Statement.	Class of Timber	Min. P_b.	Mean P_b.	Max. P_b.
A, ...	Sal	374	551	695
B, ...	Teak	289	467	567
C, ...	Sal	656	864	1,020
D, ...	Teak	608	791	951

TABLE VII.

Showing the value of E_d *as deduced from the deflection of each beam tried under each of the three loads to which it was subjected, from ordinary formula* $BD^3 = \frac{L^3W}{E_d}$.

In preparing this table, ⅝ of the actual weight of the unsupported length of each beam has been added to each of the loads said to have been applied at its middle, so as to allow of the deflection due to the weight of the beam itself, as well as for that due to the load applied to it.

of Ex-ments.	TABLE I: SAL.			TABLE II: TEAK.			TABLE III: SAL.			TABLE IV: TEAK.		
	1st load 614.	2nd load 1,167.	3rd load 1,720.	1st load 527.	2nd load 1,019.	3rd load 1,421.	1st load 19⅛.	2nd load 38¼.	3rd load 76½.	1st load 17¼.	2nd load 34½.	3rd load 51¾.
1	2,842	1,801	2,288	2,440	2,359	2,467	2,600	2,566	2,448	2,300	2,283	1,640
2	2,842	2,701	2,655	No deflection.	4,718	3,290	2,600	5,133	2,448	2,300	4,566	3,417
3	No deflection.	5,403	3,211	No deflection.	1,573	1,552	No deflection.	5,133	5,100	2,300	2,283	1,640
4	3,948	2,701	2,655	3,389	2,359	2,467	2,600	2,566	2,448	2,300	1,522	1,640
5	2,842	3,141	1,991	3,389	2,743	3,290	2,600	2,566	2,448	2,300	2,283	1,640
6	5,922	3,141	4,630	1,418	2,359	2,056	2,600	5,133	3,400	1,150	2,283	2,277
7	1,653	2,701	2,844	1,418	1,595	1,645	No deflection.	5,133	3,400	No deflection.	2,283	2,277
8	1,653	1,801	2,141	No deflection.	2,406	2,419	No deflection.	5,133	5,100	2,300	2,283	1,640
9	1,653	1,825	1,991	5,083	2,743	1,913	2,600	2,566	3,400	2,300	2,283	1,640
10	1,146	1,801	2,458	813	1,179	1,097	2,600	2,566	5,100	2,300	1,522	2,277
11	1,920	2,178	2,140	813	1,179	1,316	2,600	1,711	2,448	2,300	2,283	2,277
12	1,292	1,801	1,991	1,630	2,145	1,891	1,300	1,711	3,400	No deflection.	1,522	2,277
imum	1,146	1,801	1,991	813	1,179	1,097	1,300	1,711	2,448	1,150	1,522	1,640
imum	5,922	5,403	4,630	5,083	4,718	3,290	2,600	5,133	5,100	2,300	4,566	3,417

TABLE VIII.

Showing the values of the coefficients for calculating the strength and stiffness of Sal and Teak hitherto used, with the authorities from which they are taken.

Authority.	P_b.		E_d.	
	Sal.	Teak.	Sal.	Teak.
Roorkee Treatise, ...	905 to 1,150	Indian 666 to 1,055 Moulmein 640	4,209 to 4,963	3,978
Cunningham's Applied Mechanics (Lang's tables),	769 to 880	683 to 814	5,600	5,552
Third Circle's Specification,	769	683	4,963	4,498
Bull's Tables, ...	800	720	4,965	4,469
Molesworth's Pocket-book,	..	703	..	5,000
Hurst's Pocket-book, ..	840	560	5,000	4,493
Present Experiments, ..	550	470	2,500	2,200

J. D.

No. CCCIII.

EXPERIMENTS ON BRICK WATER TANKS.

[*Vide* Plate].

By E. W. Stoney, Esq., *B.C.E., M. Inst. C.E.*

The experiments about to be described were made by the Author, to show the influence of cross wall bond on the strength of masonry tanks; and it is hoped that they may interest readers of the Professional Papers, and induce others to make further experiments on the same subject.

Two tanks of the form and dimensions shown in *Figs.* 1 to 7, were built with walls 4½ inches thick, with stock bricks of good quality, laid in mortar composed of equal volumes of lime, sand, and surkhi, when finished they were plastered inside, half an inch thick, with mortar of similar composition; this plaster is represented in the plans and sections by black lines.

The front wall GH of tank No. 1, *Figs.* 6 and 7, was built flat against the cross walls EK, FL, without being bonded into them, but had mortar put in the joints K and L throughout. For convenience and economy the side of an existing building was used as the back wall, into which the cross walls were bonded.

Tank No. 2, *Figs.* 1 to 5, was well bonded throughout, care being taken to join the cross walls AC, BD, as strongly as possible to the side walls AB, CD; which were made long, in order to induce failure by rupture about their centres.

Experiment No. 1.

Tank No. 1 was built on the 8th of July 1878, and tested on the 23rd of August following, by pouring water slowly into it, through a zinc pipe graduated outside with feet and inches, so that the depth of water in the tank could be read off on it, and having its upper end formed into a funnel; by pouring the water through this pipe waves and agitation were prevented.

When the water reached a depth of 2 feet 4 inches, the front wall GH suddenly turned over in one piece on its lower edge, without having shown any signs of previous leakage or failure.

Experiment No. 2.

The front wall GH of tank No. 1, was rebuilt as before, touching the cross walls EK, FL; but care was taken that no mortar was used in the joints K and L, and the interior was plastered as before to retain water.

After this wall had been a month built, water was poured in as before described, and when it got to 1 foot 7 inches in depth, the front wall failed by overturning round its lower edge.

In this experiment the overturning moment of the water was opposed, only by the moment of stability of the wall, plus the tenacity of the plaster joint at each side.

Experiment No. 3.

The bonded tank, *Figs.* 1 to 5, was built on the 9th of July last, and tested on the 24th of August following, by pouring water into it as in the previous experiments; when a depth of 3 feet was reached, the bottom joint of the front wall began to leak, and this increased up to the time of failure, which occurred when the water rose to 3 feet 6 inches.

Up to the instant previous to failure, the side walls showed no signs of bulging or distortion, and deflection indicators placed against them did not move.

Finally both long walls AB, CD, suddenly bulged out, towards their centres; the back wall AB burst from the cross walls AC, BD, as shown in *Figs.* 3 and 4, turned over, and broke up in its fall, while the front wall CD returned to its original position intact.

The portions shaded in *Figs.* 3 and 4 remained standing, while the unshaded parts were carried away by and with the back wall AB.

The joints along which the work cracked are marked by heavy lines.

Comparing Experiments 2 and 3, it will be seen that the bonded tank bore before failure, more than twice the depth of water that burst the unbonded one, and an overturning moment nearly eleven times as great; so that in designing such tanks, the influence of bond on their strength, might it would seem, be taken into account with safety and economy.

Circular tanks of thin brickwork, hooped with iron, would probably prove efficient; and be considerably cheaper than the square or rectangular masonry ones generally employed at Railway Watering Stations.

Experiment No. 1.

Overturning Moment of Water $= 62\cdot5\ \mathrm{B}\,.\,\mathrm{H}\,.\,\frac{\mathrm{H}}{2}\,.\,\frac{2\mathrm{H}}{3} = 10\cdot4\ \mathrm{BH}^3$.

$\mathrm{B} = 7\cdot5$ feet, $\mathrm{H} = 2'\,4'' = 2\cdot33'$.

*Overturning Moment of Water $= 10\cdot4 \times 7\cdot5 \times (2\cdot33)^3 = 78 \times 12\cdot65 = 986\cdot70$ foot lbs.

Moment of Stability of Wall = weight of wall by half width.

„ „ „ $= \left\{8\cdot25' \times 3' \times \frac{5'}{12} \times 100 \text{ lbs.}\right\} \times \frac{5'}{24} = \frac{20625}{96} = 214\cdot84$ foot lbs.

The weight per cubic foot of wall was found by trial to be 100 lbs.

Total overturning Moment of Water = 986·70 foot lbs.

Total Moment Stability of Wall = 214·84 „ „

Difference due to strength of mortar joints K and L = 360 sq. inches in area, } 771·86

Experiment No. 2.

Overturning Moment of Water $= 10\cdot4\ \mathrm{BH}^3$. $\mathrm{B} = 7\cdot5$, $\mathrm{H} = 1'\,7'' = 1\cdot58'$.

„ „ „ $= 10\cdot4 \times 7\cdot5 \times (1\cdot58)^3 = 78 \times 3\cdot95 = 308\cdot10$ foot lbs.

Total overturning Moment of Water = 308·10 foot lbs.

Total Moment of Stability of Wall as before = 214·84 „ „

Difference due to tenacity of plaster joints 36 square inches in area, } 93·26

In this experiment the depth of water whose overturning moment would just equal the Moment of Stability of the wall, will be found to be 1′ 5″ as follows:—

$$10\cdot4\ \mathrm{BH}^3 = 214\cdot84$$

$$\therefore \mathrm{H} = \sqrt[3]{2\cdot75} = 1'\,5'' \text{ nearly.}$$

If in this instance a factor of safety of 8 be assumed, the safe working depth of water for this tank may be found to be 8 inches, which is about what the ordinary rule would give.

$$\text{Safe Working Moment} = \frac{214{\cdot}84}{8} = 26{\cdot}85 = 10{\cdot}4\ BH^3$$

$$\therefore H = \sqrt[3]{\cdot 34} = 8 \text{ inches.}$$

Experiment No. 3.

Total overturning Moment of Water $= 10{\cdot}4\ BH^3$. $B = 7{\cdot}5'$, $H = 3{\cdot}5'$
$= 10{\cdot}4 \times 7{\cdot}5 \times (3{\cdot}5)^3 = 78 \times 42{\cdot}875 = 3344{\cdot}25$

Total Moment of Stability of Wall $= \left\{ 8{\cdot}25' \times 4{\cdot}16' \times \frac{5'}{12} \times 100 \text{ lbs.} \right\}$
$\times \frac{5'}{24} = \frac{34{\cdot}32 \times 2500}{288} = 298$ foot lbs. nearly.

Total overturning Moment of Water = 3344·25 foot lbs.
Total Moment of Stability of Wall = 298·00 „ „

Difference due to bond of side walls, area of joints 500 square inches, } 3046·25

If we assume for this tank a factor of safety of 8, we have as before

= 418 = safe overturning moment.

$418 = 10{\cdot}4\ BH^3$, which gives $H = 1'\ 9''$.

It would seem therefore that a depth of 1 foot 9 inches of water might safely be put in this tank.

Summary of Experiments.

Number of Experiment.	Depth of water which caused failure. Feet	Depth of water which caused failure. Ins	Ratio of depth to thickness of tank wall. Times Wall.	Total overturning Moment of Water. Foot lbs.	Total Moment of Stability of wall. Foot lbs.	Difference. Foot lbs.	Area of joints in square inches.	Safe depth for tank with a Factor of Safety of 8. Feet	Safe depth for tank with a Factor of Safety of 8. Ins.	Remarks.
1	2	4	5·6	986·70	214·84	771·86	360	..	..	Not bonded.
2	1	7	3·8	308·10	214·84	93·26	86	..	8	„ „
3	3	6	8·4	3344·25	298·00	3046·25	500	1	9	Bonded.

28th March 1879. E. W. S.

Fig. 5.
SECTION

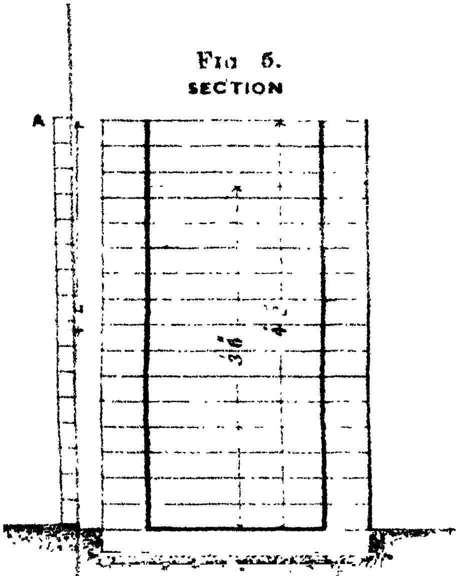


Fig. 7.
SECTION

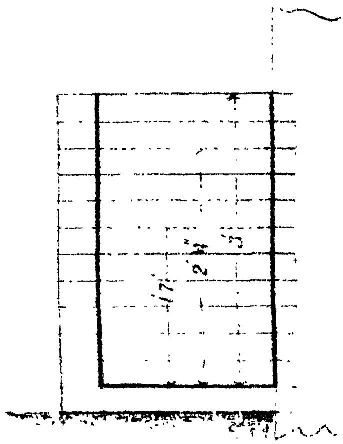
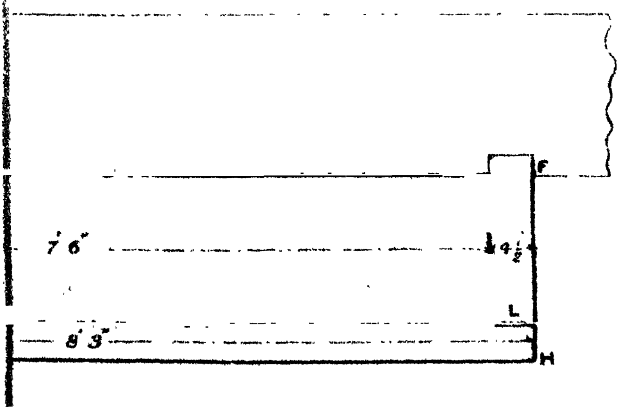


Fig. 6.
PLAN



No. CCCIV.

LOGARITHMIC LINES FOR TIMBER SCANTLINGS AND OTHER FORMULÆ.

An ingenious sheet of diagrams of Logarithmic Lines has been published by Pandit Tilok Chand, Draftsman in the office of Superintending Engineer, 2nd Circle, Panjab, which will be found useful to any one who has frequent occasion to determine the scantlings of beams, &c., on certain fixed data. The work can be obtained of the author.

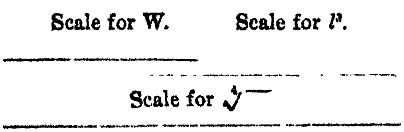
Pandit Tilok Chand gives no explanation of the construction of his diagrams beyond that they are on the principle of Logarithmic Lines, and as the April Number of the Professional Papers is not full, it may be useful to some to give a short explanation of the Logarithmic Line or Slide Rule. Practice only can make perfect in its use, and the general opinion is that it is not useful except in cases where a great many rough calculations are wanted. Those however who do use it frequently and so acquire the habit, always appear fascinated by it.

A Logarithmic Line is merely a log table scaled out. Take any length, and scale off from A, one end, with any convenient scale; 301, 477, 602, 698, &c., the logs of 2, 3, 4, 5, &c., always of course counting from zero at A, and at these points write 2, 3, 4, &c. Then the length from zero to any one of these figures represents the log of that figure graphically. Make another scale B exactly similar. These are the A and B scale of any carpenter's rule. Now if B scale be slid along A, so that B zero comes to any point, say C, on A scale, then at any point D, further

A C D

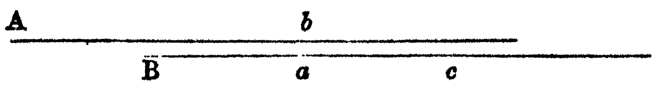
on, the length AD is the length of the log of AC + the log of BD, or the log of $\overline{AC \times BD}$, and the figure at D on the top scale will of course be the product of that at C on A, and that at D on B. Thus the multiplication is done. Division is exactly similar as the reading at C is the quotient of AD $\div$ BD.

Scales it will be at once seen can be made to represent anything, for the same *divided* scale as A or B could have been *numbered* 2, 3, 4, &c., not at the logs of 2, 3, 4, as was done, but at logs of the squares, or cubes or π times these numbers, and thus adding the length on such scales will multiply by the square, cubes, &c. Pandit Tilok Chand's first example will illustrate this. The formula for stiffness of a deodar beam taking breadth two-thirds of depth, and using Panjab coefficient of safety gives $d = \sqrt[4]{\frac{W.l^3}{40}}$. He constructs three logarithmic lines, one as A or B numbered plainly for W, one for l^3, *i.e.*, numbered 2, 3, &c., as the cubes of those numbers, and one for 4th powers. He places the two first alongside, but pointing opposite ways with the zero of the l^3 scale at 48 on the W scale. Then the distance between any reading on W and any reading on l^3 will be the log of the expression under the radical sign *i.e.*, log W — log 48 + log l^3, and this placed on scale of 4th powers reads d the depth required. Thus one application of the compasses gives the value of the above formula.



Various other simple formulæ have been scaled out in the same way, and the sheet forms a very handy office record, and the principle might be applied to any similar cases where frequent rough calculations have to be made with the same formula.

The applications of the slide rule are of course various. Thus with two plain scales the reading on A opposite c is log b + log c — log a,



or a fourth proportional to a, b and c, and there are many simple operations that can be performed by it. The impossibility of dividing and numbering the scale in the limited space is of course the great drawback to accuracy.

To meet this a spiral rule has been designed by Mr. G. Fuller, M. Inst. C.E., Professor of Engineering, Queen's University, Ireland. The descriptive pamphlet, price sixpence, is published by Spon, and the instrument is made by Stanley, price 50 shillings. The spiral line winds round a cylinder, and is equal to a straight rule 83 feet long. This allows of numbering to three figures, and gives results correct to one ten thousandth the part of the whole.

There is however another aid to calculation, which will be found very practically useful in long estimates and any tabular work. This is a multiplication table containing products of any pair of numbers within 1000 each. It is very plainly got up, quarto size, and will soon repay its cost in any office where there is much calculation to be done. In filling in the *bd* columns of an earthwork estimate, *e. g.*; where *b* is a fixed quantity for miles perhaps, it saves great labour and ensures accuracy. This and the College coloured sheet of sd^2 make a complete earthwork estimate table. The title of the work is Dr. A. L. Crelle's Rechentafeln, Berlin, 1875, and Thacker Spink & Co., Calcutta, have supplied several lately at Rs. 12-4-0, including postage.

A. M. B.

No. CCCV.

INUNDATIONS IN THE JALANDHAR DOAB.

[*Vide* Plate.]

By C. G. Faddy, Esq.

The recent disasters to the Scinde, Panjab and Delhi Railway between Phillor and Wazir Bholar having by their extent and magnitude drawn considerable attention to the subject, I append a few notes and remarks as to their origin and cause, as well as a few hints, which, if acted on, would, in my humble opinion, tend greatly to mitigate, if not altogether prevent, their repetition in future.

The Jalandhar Doab is in shape a large and irregular polygon, its boundaries being the Beas, the Siwaliks, and the Sutlej.

The Sutlej leaves the hills at Babhor and runs almost south, past Kirathpur and Rupar, where it takes a westerly direction flowing between Ludhiana and Phillor, as far as Aliwal, then it turns about north-west as far as Harriki, where it is joined by the Beas.

The Beas debouches from the Siwaliks near the old cantonments of Hajipur, it runs thence in a direction almost south-westerly, skirting the Hoshiarpur, Kapurthala and Jalandhar districts.

The Siwaliks rise abruptly from the Sutlej opposite Rupar, and run almost north-west, terminating again at a place called Tagan Deo near Hajipur, about three miles from the Beas. The Siwaliks are very nearly 90 (ninety) miles in length, are of pliocene formation, consisting of strata of sand, alluvial earth, clay, boulders, shingle, and conglomerate, and in this district there are two ranges, the outer and inner Siwaliks, with their inner slopes terminating in what is called the Sohan valley, part of the drainage of which falls into the Sutlej, and the rest, which is comparatively speaking insignificant, into the Beas.

These ranges were once densely covered with vegetation, Mango, *Mangifera Indica;* Sisham, *Dalbergia Sissu;* Babul, *Acacia Arabica;* Phulahi *Acacia Modesta;* Aonla, *Emblica Officinalis;* Cheel, *Pinus Longifolia;* Mendar, *Dodonia Burmanniana,* &c., forming dense jungles and forest, the resort of tigers, leopards, bears, and elephants. I am speaking of a time not long past. Ranjit Singh often hunted in these jungles, and till within the last three or four years, old men were living who recollected the last elephant killed at Santokhgarh in this district.

When the country was annexed after the Sutlej campaign, security to life and property, fixed and light assessments, the usual concomitants to British rule, ensued, a regular settlement was made, and in the course of settlement the Gujars and other villagers became invested with rights which neither they or their fathers ever dreamed of, and in the settlement of the villages in the outer Siwaliks, the village boundaries were without any enquiry, or due investigation of right, run straight up to the watershed on either side, and the villagers had full rights to shoot, clear jungle, and fell timber, as they wished.

It was not long before the results of this reckless system of jungle clearing became manifest, the *chos* or mountain torrents enlarged themselves, extending both in length and breadth over the face of the country, spreading desolation far and wide; bodies of water, hundreds of yards in breadth, laden with silt detritus and deposit from the hills, would spread over scores and scores of acres of highly cultivated land, turning them in a few hours into wastes of sand.

The slope of the submontane country is excessive, and in some places more than 50 (fifty) feet in a mile; this tract is known in local phraseology as the *khandi,* it is more or less devoid of vegetation, and seldom yields more than one crop in the year.

The establishment of cantonments at Jalandhar, Makeria,* Hajipur,* Budhipind,* Hoshiarpur,* Kartarpur,* gave rise to an enormous demand for fuel. The railway works from Phillor to the Beas, and the Sirhind Canal headworks at Rupar, considerably increased this demand, which had its source of supply in these hills, which have now been utterly denuded of vegetation, and have at last begun to fail the Gujars as grazing grounds for their cattle.

* Abandoned shortly before the Mutiny of 1857.

All the *chos* in this district have doubled and tripled in extent since annexation of the Province, and now carry their waters far down into the Jalandhar district and Kapurthala State.

In the Hoshiarpur district, in addition to the Beas and Sutlej, there are three subsidiary drainage systems.

I. The Eastern Beyn, which has its rise near Ghurshankar, about 25 miles from the Sutlej, after a very tortuous course it enters the Jalandhar district, and about midway between Phagwarah and Jalandhar was crossed by two bridges, one carrying the railway, the other the Grand Trunk Road.

The railway viaduct was destroyed in August 1878, the Grand Trunk Road viaduct sharing a similar fate in September of the previous year.

In this district the drainage of nearly 300 square miles of country finds its way into the Eastern Beyn.

II. The drainage line passing Jalandhar city and cantonments. For some years past considerable anxiety has been caused by the great damage caused yearly to the city and civil station by floods, which of course have their origin in the Siwaliks.

Most of the *chos* have their own drainage lines well defined, but in very heavy floods, when the waters rise to a great height, it is impossible to ascertain their watersheds so to speak, and this is very marked in the case of the inundations which occur at Jalandhar.

The *cho* which flows past Hoshiarpur, finds its way into the Eastern Beyn, but last year during the floods of August 20th, 21st, owing to the great rise of water in the Beyn, the Hoshiarpur *cho* was headed up to an exceptional height, flowed over its natural boundaries, straight down into Jalandhar cantonments, and thence on to the city.

The action of the floods last year was intensified in extent and duration beyond anything ever previously witnessed.

Jalandhar is 25 miles south-west of Hoshiarpur, and about the same distance due south of Tanda, it is connected with both these places by road, one metalled and bridged and the other partially so.

A glance at the map will show that the drainage crosses the Jalandhar and Tanda road in a south-westerly direction, intersecting it in numerous places. Notwithstanding this, *some one* had the road raised some feet without making the least provision for waterway, the result was that the floods came down and were deflected back on to Jalandhar, playing unheard of havoc with the town and railway embankment, which latter in former years was scarcely ever damaged.

This flood was due to a rainfall of 25 inches in 36 hours, the heaviest yet known in this Doab.

III. The Western Beyn has its rise at a place called Unchi Bassi, between Makeria and Dasinyah; it flows through what is termed the "Chamb Chak" or a string of marshes and swamps, it eventually finds its way into the Beas crossing the railway between Kartarpur and Wazir Bholar.

All the *chos* between Hurriana, Dasinyah, and Makeria, crossing the part on the map coloured yellow, find their way into this Chamb, and in flood come down roaring torrents from 50 yards to half a mile in breadth, with a depth of from 3 to 4 and 5 feet, the excessive slope of the country makes matters worse, and nothing can resist the force with which the waters descend.

There is a tradition to the effect that in former ages the Beas used to have its course some six or seven miles more to the east, or in other words flowed directly beneath Dasinyah, Tanda, and Zahurah, and thence onwards to where Kapurthala at present stands.

My own personal observations have tended to confirm me in this belief. Our main road from Hoshiarpur to Battala *viâ* Shri Har Govindpur after passing Tanda, has a sudden dip of nearly 30 (thirty) feet in less than a quarter of a mile. After this the incline is very gentle, not more than 10 (ten) feet in 2½ miles till it crosses the Beyn, where the land again slopes up as far as the village of Rarra, which is about one mile from the Beas.

These facts I ascertained nearly three years ago, having occasion to take levels, &c., for a new bridge on this road.

The Chamb as I before said is comprised of a string of marshes and swamps about 15 (fifteen) miles long in this district, but extending down past Kartarpur into the Kapurthala State.

These marshes run almost parallel with the Beas.

My theory is that in ages long ago, owing to certain causes of which we are ignorant, the Beas began to shift its course gradually westward, till in the course of time its extreme point of divergence was attained. Whilst

NOTE.—The lands in the Chamb Chak are not cultivated, and in technical phraseology known as *ghair mumkin*; in this District there are nearly 10,000 acres of such land.

these causes were in operation, the course of the stream became somewhat tortuous, the usual results followed, its discharge became arrested, silt was deposited, and the level of the bed was raised; year by year as the floods came down the tendency to overflow its banks became more marked, and the surplus water, so to speak, was spread over a wider area. The silt and alluvial soil held in solution was precipitated over an area equally extended, the strata thus formed being thicker nearer the river. and decreasing gradually as the extreme limit of inundation was reached,

This in my opinion accounts for the fact of the slope of the country being from the river.

The Beas has again commenced to shift its course, and from a careful measurement taken through a series of years,* it is beyond all doubt that this stream desires to revisit its old bed, and is year by year cutting more and more into the left bank, and in each succeeding flood the level to which the Beas water has to rise before it can overflow into the Chamb is decreasing, consequently each succeeding flood is more disastrous in its effects lower down the valley.

From my own levels, and from some taken by Executive Engineer, Jalandhar,† it has been ascertained that the waters of the Chamb are some feet *lower than the bed* of the Beas.

During the floods the Beas brings down more water than it can hold, and at various places, more especially the villages of Motsari, Pekhowal, Khatana, Habibchak, and Abdullapur, where the Beas is cutting into the left bank about 300 (three hundred) yards yearly, this water overflows, pours into the Chamb, mingles with the Beyn, crosses our Hoshiarpur and Shri Har Govindpur road,‡ and finds its way down to the Grand Trunk Road, breaches that wherever it can, and then damages the Scinde, Panjab and Delhi Railway to a terrible extent yearly, a very heavy bill to meet no doubt, and until measures are taken to check this evil,

* I refer to the patwaris yearly measurements of alluvion and diluvion, which are on the whole very accurate; these measurements are checked by Tahsildars, Native and European Assistant

† T W. Knowles, Esq., C.E, Exec. Engineer, 2nd Division Lahore and Umballa Road, to whom is the credit due of having first drawn attention to the subject.

‡ Our waterway consists in a length of 80 chains as follows:—

1	Bridge	2	spans	15	feet	each	=	30	feet	or 4700 square feet of waterway, giving an average headway of 10 feet.
1	"	6	"	15	"	"	=	90	"	
1	"	6	"	15	"	"	=	90	"	
1	"	6	"	15	"	"	=	90	"	
1	"	3	"	40	"	"	=	120	"	
1	"	1	"	50	"	"	=	50		

Total 470 running feet.

this bill will be run up over and over again, till some fine day it may occur to the Railway Engineers that it would have been cheaper in the first place to have had a bridge from Kartarpur to Wazir Bholar.

I have heard it said, of course by people who have never been near this part of the country during the floods, that the Beas water does not, and cannot, overflow into the Chamb. Statements like this need to be met with facts. I ask why were not the Railway and Grand Trunk Road embankments and viaducts damaged during the cold weather of 1876-77, 1877-78, when our local rains were exceptionally heavy. All our *chos* were in flood more or less, and a great many of our *chos* find their way into the Beyn and Chamb. I will quote an extract from a diary of mine, August 1876.

"There had been no rain in Hoshiarpur for nearly 24 hours. On the evening of the 16th I started for Tanda, reaching that place during the night; was informed by Overseer that no rain had fallen in the parganah since the morning of the previous day; the Beas had been in flood but was going down. Next morning Overseer informed me that owing to heavy rain in Kangra and Kulu, the water was again rising. Would I go and inspect the Alampur causeway which had failed some days previous, and as a boat was the only means of locomotion, he had procured one. We started about 11 a.m., the day cloudy and a strong south-east wind blowing.

"I got down to our nearest viaduct in the Beyn valley to find the whole valley under water from within a mile of Tanda to the Gurdaspur bank of the Beas. The rush of water was considerable, and it was only by means of an extemporised mast and sail that we could make any progress in our journey 'across country,' and it took us very nearly three hours to get up as far as Alampur. What a sight we beheld, the tops of trees and villages only to be seen, everything else submerged, the water a deep tinged colour, which is derived from the peculiar soil held in solution and brought down by the Beas from the Himalayas, and especially the Kulu valley, hence the name it goes by *Kulu ka pani.* The set of the current was from north-west to south-east from the river and against the wind. We got to Alampur by about 3 p.m., had a look at the causeway, or rather the guide posts in the roadway, for there was a head of 4 feet of water running over it. A few enquiries were made. We went up about a mile above Alampur, saw what was to be seen, intending to return by the Chamb;

but this we were not fated to do. We were caught in the strong current of the Beyn and carried at once down the stream, in the direction of the causeway, the boat going anyhow, broadside, stern or bow foremost. A rudder over was put out over the stern, and we got its head straight and managed to get over the causeway without very much difficulty. When it became dark the wind went down, and we had no moon no stars to guide us or show us where we were. Suddenly we were bumped against some submerged trees, getting clear of these we saw a dark mass looming ahead of us, it was the Beyn bridge. We just had time to steer straight for the centre span, and crouch down in the boat as we 'shot the bridge.' I touched the soffit at the crown of the arch as we passed."

In the cold weather of 1876 I visited the places where the Beas finds its way into the Chamb, and was then convinced that it is only a question of time; it may be four, five or ten years hence; but sooner or later the Beas will, after having cut into its left bank a certain distance and finding nothing to retain it, pour the greater part of its waters into the Chamb, regain its old bed, and sweep clean everything before it, villages, crops, roads, bridges and embankments as far as Sultanpur in the Kapurthala State.

Protective measures are urgently needed, and I would suggest the following:—

I. A complete scheme for reboising the Siwaliks from the Sutlej to the Beas, and similar operations on a large scale far up the Beas valley.

II. Extensive operations comprising bands, spars, training works, &c., in the Beas valley, for the purpose of straightening the course of the river, deepening its channel, and deflecting it as far as possible, and wherever practicable on to the Gurdaspur bank which is high, and where little or no damage could result.

I. Reboisement—

The Forest Act of 1878 empowers Forest and District officials to carry out all measures requisite to preserve and "reboise" certain tracts from the destructive results consequent to a reckless denudation of forest area. To carry out the provision of this Act in Hoshiarpur, an Assistant Conservator of Forests with a subordinateesta blishment consisting of—2 Foresters, 50 Rakhas or Chowkidars, and 8 Jemadars is needed. Annual cost not to exceed Rs. 6,000, and the cost to be borne by the Hoshiarpur Local Funds.

It has been calculated that one-fourth of the actual average of each hill village is ample for the requirements of the inhabitants.

Allowing to each village 4,000 (four thousand) bigahs of land, this area should be demarcated into blocks of 100 (one hundred) bigahs each, numbered consecutively from 1 to 40. Operations being started say in 1880, blocks numbers 1, 11, 21, 31, 2, 12, 22, 32, 3, 13 would be made over to the Gujars to cultivate, graze cattle, &c., thereon the remainder to be enclosed fenced off, and the provisions of the Act to be vigorously enforced, grazing, clearing jungle, &c., to be made penal.

At the expiration of seven years, say by April 1887, blocks numbers 23, 33, 4, 14, 24, 34, 5, 15, 25, 35 to be made over, broken up and cleared for cultivation and pasture, the first lot or series to be taken over and brought under conservancy, and so on in regular succession, in this manner three-fourths would always be under forest conservancy. In this manner the interests of the villagers and the estate in general would be amply protected; of course as the forest grew valuable each village would have to contribute its share of cost of subordinate establishment.

It may be urged that the prices of most commodities would rise, owing to the scarcity of fuel, and that the Gujars, Paharis and villagers of montane tracts would suffer from such an infringement on their rights as would be entailed by bringing these hills under forest conservancy; but allow me to state that under the present system ten or twelve years hence these very rights would have no existence whatever, as it is highly probable, nay almost certain, that by that time these Siwaliks would cease to bear vegetation of any sort. Moreover in the Hoshiarpur parganah alone there are 35,000 bigahs of land brought to that state known as *choburdi* or deluviated, representing a dead loss to Government of Rs. 50,000 per annum in land revenue, and the total loss in this district alone may be put down as considerably over Rs. 100,000, per annum.

The above would be the cheapest method of dealing with the evil, though in my opinion it would be true policy if the Government were to buy up large tracts of land in the Siwaliks, having their own reserves and plantations, a valuable legacy for future generations, a sure and prolific source of revenue.

The Grand Trunk Road and Railway run almost parallel to each other, and cross the drainage throughout the Doab: the evil effects arising from excessive floods are alternately ascribed to one or the other of these works, the railway however being in public opinion the chief delinquent; when the Delhi Railway was first projected, aligned and works started the able Engineers who drew up the project gave what was under the conditions of those days ample waterway throughout this Doab; but from Phillor to Kartarpur, the floods due to a reckless system of "deboisement" in these hills, have increased in severity, the failure of numerous viaducts from year to year in the Doab culminating in the grand disaster of 1878 confirm this theory.

Nothing short of a complete system of reboisement in the Siwaliks, will effectually protect the country from Phillor to Kartarpur, and with it the Railway and Grand Trunk Road, and to be effectual it must be complete, half measures will do no good.

In the Beas valley we have to deal with the Beas as the chief, if not sole source of evil, to mitigate which a costly and arduous struggle must be waged with nature; a struggle of the result of which we need not despair, provided prompt action is taken.

In the accompanying Sketch Map will be seen a road running parallel to the Beas, from the town of Miani to the village of Kolian, wherever the level of this road is sufficiently high it checks the ingress of water into the Chamb, but in most places, where the level has sunk, the water in flood pours over it unchecked.

One of the first measures I would advocate would be the raising of this road at least three feet above "highest flood level," this has been advocated by more than one Engineer who has visited this part of the district.

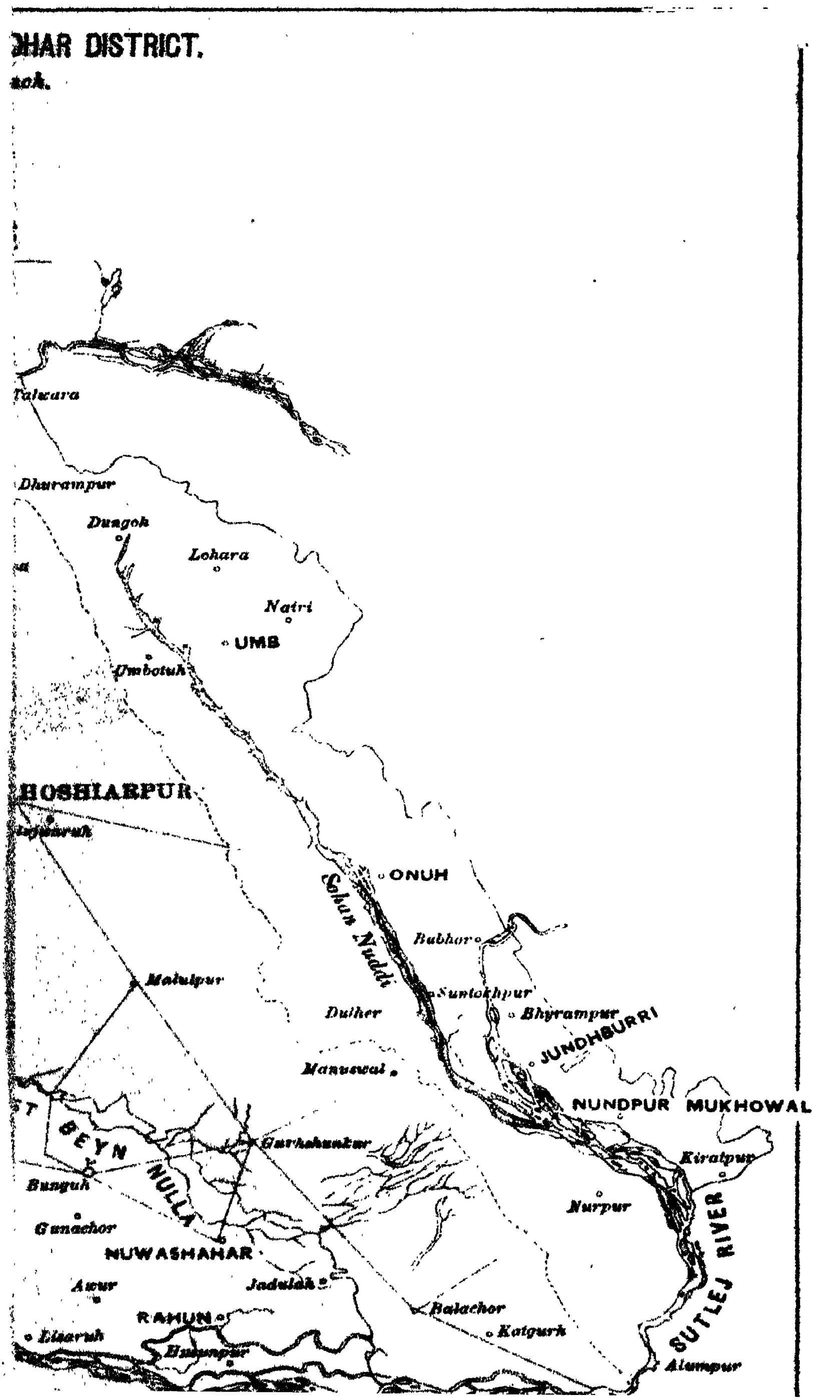
I have been informed on good authority, that the Kapurthala State has professed its readiness to spend a couple of lakhs of rupees, provided the Government and Railway would take the initiative in the matter.

The operations would be costly, and would extend over a period of some two or three years, and would require at least Rs. 500,000, which might be met as follows—

	Rs.
Kapurthala State, ...	2,00,000
Scinde, Panjab and Delhi Railway, ...	2,00,000
Panjab Government, ...	50,000
Hoshiarpur Local Fund, ...	30,000
Jalandhar, ...	20,000
Total, ...	5,00,000

This may sound a large sum, but until the Kapurthala State, the Railway and Grand Trunk Road can be protected from the disastrous effects of the overflow of the Beas into the Chamb, I do not think that money or exertions should be spared. Moreover the land reclaimed in this district alone would yield very nearly Rs. 15,000 land revenue to Government, or 3 per cent. on the total outlay. The maintenance of our communications with the North-West Frontier is of paramount importance, with a gap 25 miles long, no road, no bridges, no embankments, and a large river to cross after that, it is impossible to depict the disastrous effects which might have resulted had Government been compelled to push up 25,000 troops to the Frontier during August and September, supposing Shere Ali Khan had chosen to precipitate the present crisis six weeks earlier than he did.

C. G. F.



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Bhyrampur
JUNDHBURRI
Mulalpur
Duther
Manuswal
NUNDPUR
MUKHOWAL
Kiratpur
BEYN NULLA
Garhshunkur
Bunguh
Nurpur
Gunachor
NUWASHAHAR
SUTLEJ RIVER
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Kotgurh
Lisaruh
Alumpur

MAP OF THE HOSHIARPUR AND

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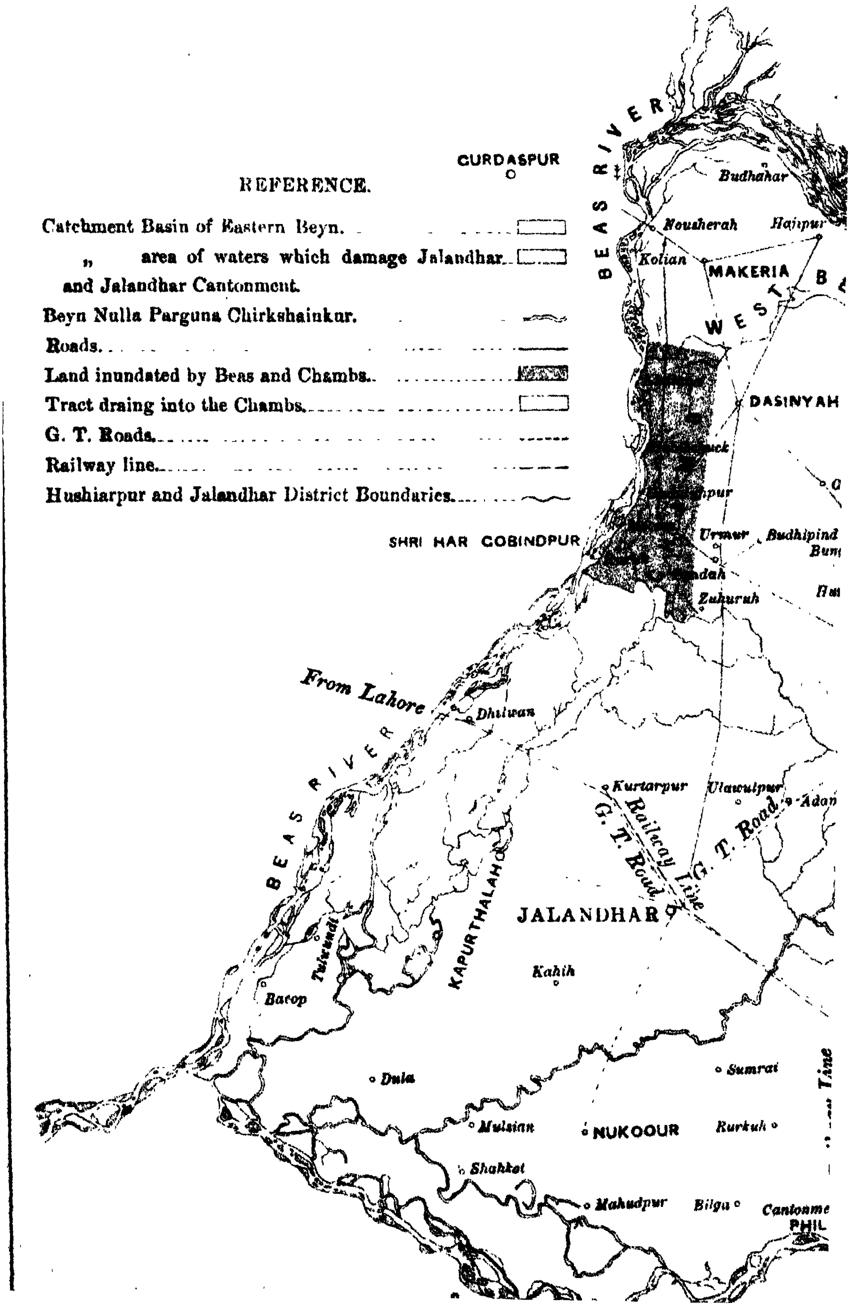

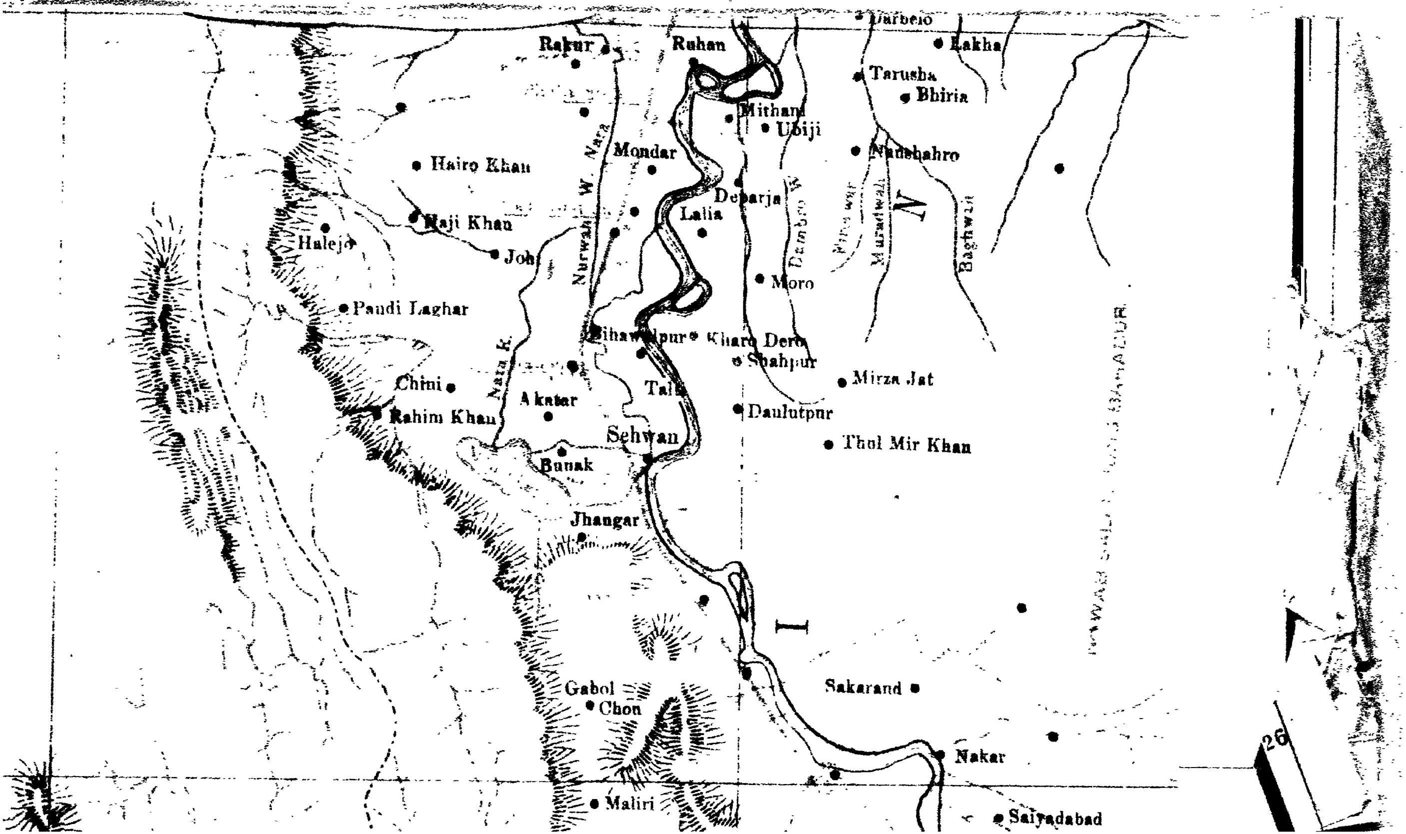
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Tarusha
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Deparja
Lalia
Haji Khan
Halejo
Joh
Nurwah W.
Nara
Dambro W.
Murad wah
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N
Moro
Pandi Laghar
Bihawalpur
Kharo Dero
Shahpur
Mirza Jat
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Nara R.
Akatar
Tala
Daulutpur
Rahim Khan
Sehwan
Thul Mir Khan
Bunak
Jhangar
I
Gabol
Chon
Sakarand
Nakar
Maliri
Saiyadabad
26

PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING

[SECOND SERIES.]

EDITED BY

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CONTENTS.

As no Loose Copies of the Professional Papers are now kept in Stock, Subscribers wishing extra copies of any separate Articles in the present Number, should make early application to the SUPERINTENDENT OF THE PRESS, so as to reach him before the type is broken up. The price of Loose Copies is reduced to one anna per 8 pages, or part of 8 pages, and half an anna a Plate, up to a maximum of eight annas; but requisitions can only be complied with if received before the type is broken up. To facilitate this, the following list of Articles received for publication is issued. It will not, it should be remarked, bind the Editor to issue all Articles entered in case more interesting matter is received.

The articles now in hand are—

1. Mysore Cultivation and Irrigation. By Major Fraser, R.E.
2. Solid Iron Pile Bridges. By Lieut.-Col. C. A. Goodfellow, R.E.
3. Helical Cutter for Well sinking. By E. W. Stoney,

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A. M. B.

No. CCCVI.

ENQUIRY INTO THE POSSIBILITY OF THE USE OF WIND POWER FOR IRRIGATION.

[*Vide* Plate.]

No. C-133 W, dated 19*th February*, 1877.

Note by COL. H. A. BROWNLOW, R.E., *Offg. Chief Engineer, Irrigation Works, N.-W. Provinces, on a letter from Mr. F. B. Thuber of New York, inviting attention to the desirability of using Wind-mills as a means of raising water for Irrigation in India.*

I HAVE for many years held the opinion that the wind in the N.-W. Provinces of India is far too uncertain and variable in its strength to admit of its being usefully applied as a motive power.

It blows for only two or three months with any steadiness, and is practically calm for the remainder of the year, but is apt to make up for deficiency of force at other times by occasionally coming in gales and cyclones which would level the wind-mill.

Being, however, unwilling to put forward this opinion officially unsupported by any facts, I asked my Personal Assistant, Mr. Nelson, to see how it would stand the test of comparison with anemometrical registers, and append to this Note the results of his enquiries.

They seem to me fully to support my view of the matter, and I would suggest that enquiries of a similar nature might advantageously be made in other parts of India. It would then be known with some degree of certainty where wind-mills could be profitably erected, and the frequently recurring suggestions for their use would either be definitely answered, or take useful shape.

Annexure to Offg. Chief Engineer's No. C133W, dated 19th February, 1877. *By* P. NELSON, ESQ., *Asst. to Chief Engineer.*

Smeaton, in a table at the end of his "Experimental papers on the power of water and wind to turn mills, &c., &c."* says, that when the velocity of the wind is 1 mile an hour it is "*hardly perceptible*;" when 2 and 3 miles an hour, it is "*just perceptible*;" and when 4 and 5 miles an hour, it is a "gentle, pleasant wind:" from this I gather that a "*light breeze*" (mentioned by Mr. Thuber) is rather more than 4 miles an hour, or about 6 feet a second.

Smeaton does not say definitely what is the least wind-velocity required to move the arms of a wind-mill with effect, but it appears from the general tenor of his essay, and the figures in his table, that 4½ feet per second is the minimum; this equals a little more than 3 miles an hour. (I have consulted other works without being able to obtain information on this point).

Three miles an hour is equivalent to 72 miles per diem; 4 miles an hour equals 96 miles a day. Appended is a Table (A.) showing the wind velocities of five stations in the North-West Provinces and Oudh, from November 1871 to November 1874 (a period of 37 months), abstracted from the tables published monthly in the N.-W. Provinces Gazette by the Meteorological Reporter. A study of the table shows that—

I. *At Roorkee*—The average velocity of the wind exceeded 3 miles an hour in June and July 1872; February, March, May, June and July 1873; and May, June and July 1874, or in 10 months out of the 37.

A velocity of 4 miles an hour was reached in May and June 1873, or in 2 months out of 37.

II. *At Bareilly*—The velocity exceeded 3 miles an hour in November and December 1871; in February, March, April, May, June and July 1872; in February, March, April, May, June and August 1873; and in March, April, May, June, August and September of 1874, or in 20 months out of 37.

The velocity of 4 miles an hour was exceeded in the months of February and June 1872; March, May and June 1873; and May and August 1874, or 7 months out of 37.

III. *At Agra*—Three miles an hour was exceeded in December 1871;

* Tracts on Hydraulics, edited by Thomas Tredgold, Civil Engineer, pages 47 to 78, for reprint see on.

in January, February, March, April, May, June, July and August of 1872; in January, February, March, April, May, June, July, August and September of 1873; and in January, February, March, April, May, June, July, August and September of 1874, or in 26 months out of 37.

Four miles an hour were reached in February, April, May, June and July of 1872; in March, April, May and June 1873; and in February, March, April, May, June, July and August of 1874, that is, in 16 out of 37 months.

IV. *At Lucknow*—The wind velocity exceeded 3 miles an hour in February, March, April, May, June and July 1872; in February, March, April, May, June, July and October 1873; and in February, March, April, May and June of 1874, that is, in 18 months out of 37.

The velocity of 4 miles an hour was reached in June and July 1872; in March and May of 1873; and in March, May and June of 1874, or in 7 months out of 37.

V. *At Benares*—Three miles an hour were exceeded in March, April, May, June, July and August 1872; in March, April, May, June, July, August and September 1873; and from January to September (inclusive) in 1874, or in 22 months out of 37.

Four miles an hour were exceeded in May, June and July 1872; in May, July and September 1873; and in February, March, April, May, June, July and August 1874, altogether in 13 months out of 37.

The ordinary course of agriculture in these Provinces requires that irrigation for the Rabi (cold weather) crops should be in progress during November, December, January and February; and for the Kharif (or hot weather) crops, in April, May and June. Only in very exceptional years would irrigation be generally resorted to in July, August, September and October, and even if the wind were favorable, it would scarcely pay to erect mills to be used only once in 10 years or so.

It will therefore be convenient to consider the Rabi and Kharif separately: and further to notice the number of calm days in each month, and the variation of the wind; for this latter purpose I have collected the anemometrical results published for the year 1875.

Rabi.

November.—During the five years 1871 to 1875 (inclusive), the wind was only *once* (1871) of sufficient velocity to move the sails of a mill, and that only at one station (Bareilly) out of five. The month is usually calm.

December.—In 1871 the wind was above the minimum 3 miles an hour, but only at two stations (Bareilly and Agra) out of five. Decembers 1872, 1873, 1874 and 1875 were all *calm* months at all stations, during which mills would not have worked.

January.—During the years 1872, 1873, 1874 and 1875, the wind was three times above the minimum at Agra (1872, 1873 and 1874), and once at Benares (1874). At all other places it was below. At no place was the velocity of 4 miles an hour reached. It is therefore manifest that wind-mills would be of no use in January.

February.—In 1872 the wind at three* stations out of five was above the minimum, and in two of these (Bareilly and Agra) above the rate of 4 miles an hour. In 1873 the wind at four stations out of five was above the minimum, but at none above the "light breeze" figure. In 1874 the wind was above the minimum in three† out of five stations, and in two of these it was a "light breeze;" and lastly, in 1875, the same three stations show a velocity above the minimum, as did so in 1872. Altogether February is a more windy month than any of the three preceding; yet the wind is so variable, and so often below 3 miles an hour at so many stations, that it may safely be said that wind-mills would not work.

It is clear from the foregoing that wind-mills could not be worked during the Rabi months, and the Rabi is the most important season in the year, especially where irrigation is practiced from wells, for the area usually irrigated in Rabi is about four times that irrigated in Kharif.

KHARIF.

April.—In 1872 the velocity was above the minimum in four stations out of five, but in only one (Agra) did it blow a "gentle breeze." 1873 was the same as 1872. In 1874 the wind was variable, but in three places exceeded 4 miles an hour, and 3 miles in four places. In 1875 the wind was generally above the minimum, and in two out of four stations was more than 4 miles an hour. During this month, therefore, wind-mills would probably work, except in the upper districts of the Ganges-Jumna Duab.

* Bareilly, ... 101 per diem.
Agra, ... 107 ,,
Lucknow, ... 83 ,,

† Agra, ... 102 per diem.
Lucknow, ... 89 ,,
Benares, ... 109 ,,

May.—In 1872 the wind was above the minimum in four out of five stations, and exceeded 4 miles an hour in two places (Agra and Benares). In 1873 the velocity generally exceeded 4 miles an hour, as it did too in 1874, except at Roorkee, where the mean was just 3 miles an hour. The Meteorological Reporter says for 1874, that calms were frequent. In 1875 also the velocity was generally over 4 miles an hour.

In the month of May, therefore, it may be accepted that wind-mills would work fairly well.

June.—This is usually a windy month, but the wind is variable.

For the purposes of Kharif irrigation, it would appear that wind-mills are feasible; but the fact should not be lost sight of that during the three months, April, May and June, violent sandstorms, capable of throwing down large trees, are of frequent occurrence, and any mill to be worked during those months must needs be of great strength and consequently very expensive.

TABLE A.

Anemometrical Observations at five Stations in the N.-W. Provinces.

Month.		Roorkee. (4) Mean Direction.			Roorkee. Velocity in miles per diem.	Bareilly. (6) Mean Direction.			Bareilly. Velocity in miles per diem.	Agra. (7) Mean Direction.			Agra. Velocity.	Lucknow. (9) Mean Direction.			Lucknow. Velocity.	Benares. (12) Mean Direction.			Benares. Velocity.	Remarks.
			°				°				°								°			
1 November,	...	N	55	W	19·7	N	36½	W	80·5	N	79½	W	71·1	...	...	...	39·4	N	58½	W	30·6	Direction variable; 12 to 14 calm.
December,	...	N	45	W	24·1	W	42	N	80·8	N	14	W	77·9	...	...	...	39·1	E	33½	N	32·5	Direction constant; 1 day calm; violent at 11-30 p.m.
2 January,	...	N	6	W	47	N	3	W	66	N	14½	W	94	...	...	...	59	N	25	E	39	Direction constant.
February,	...	N	21	W	67	N	34	W	101	W	21	N	107	...	.	...	83	N	34	W	65	
March,	...	N	38	W	42	W	41	N	85	W	27	N	90	...	...	...	93	N	4	N	86	
April,	...	N	7	E	44	W	41	N	81	W	6	N	116	...	...	...	78	W	7	N	78	Direction variable.
May,	...	E	13	N	66	N	13	W	83	W	18	N	139	...	...	...	89	W	4	N	98	Direction changed during day.
June,	...	E	30	S	94	E	5	S	108	N	10	E	141	...	...	...	117	S	6	E	105	
July,	...	E	42	S	85	E	17	S	80	E	3	N	142	...	...	...	119	S	36	E	116	Wind in morning, calm in evening.
August,	...	S	44	E	56	E	16	S	62	N	15	W	90	...	...	...	55	S	2	W	77	Afternoons and evenings calm.
September,	...	S	5	E	51	E	34	N	42	W	24	N	57	...	...	...	48	S	44	W	56	Calm days outnumbered windy days.
October,	...	S	31	E	34	W	35	N	19	W	12	N	47	...	...	...	21	W	3	S	38	
November,	...	S	8	E	30	W	44	N	17	W	29	N	58	...	...	...	23	W	30	S	29	Calm days far outnumbered other days.
December,	...	S	10	E	20	W	22	N	23	W	11	N	52	...	...	...	27	W	3	N	28	Calm nights; just enough force in day to show direction.

1873	January,	...	S	16	W	61	W	29	N	41	W	10	N	85	...	...	...	56	W	5	S	54	
	February,	...	N	19	W	75	W	26	N	72	W	3	S	86	...	...	...	79	W	3	N	65	
	March,	...	S	35	W	87	S	44	W	104	N	3	W	109	...	...	...	99	W	8	S	87	
	April,	...	S	20	W	67	W	8	N	78	W	3	N	115	...	...	...	85	W	2	S	86	
	May,	...	W	29	N	111	W	42	N	117	W	15	N	129	...	...	...	125	W	12	N	102	
	June,	...	S	15	W	147	E	13	S	103	W	10	N	122	..	...	...	91	W	1	N	94	
	July,	...	S	28	E	87	E	10	S	69	E	29	N	87	...	...	...	82	W	21	S	103	
	August,	...	S	11	E	62	N	30	E	76	W	13	S	92	...	...	...	53	N	10	W	79	
	September,	...	S	6	E	48	N	15	E	68	N	26	W	76	..	...	...	63	W	32	S	99	
	October,	...	S	14	E	34	W	24	N	30	W	4	S	39	...	...	...	90	W	4	S	29	Calm at mid-day.
	November,	...	S	6	W	29	W	43	N	26	W	19	N	37	...	...	...	13	W	8	N	20	Calms prevailed.
	December,	...	W	24	N	20	W	10	N	25	W	23	N	34	...	...	...	38	W	6	S	65	Calms and gentle winds.
1874	January,	...	W	5	N	45	W	42	N	50	N	42	W	78	...	...	...	65	W	33	S	80	
	February,	...	N	42	W	52	W	23	N	66	W	8	N	102	...	...	...	89	W	8	S	109	
	March,	...	N	38	W	68	W	15	N	77	W	12	N	123	...	...	...	103	W	11	S	129	Calms frequent.
	April,	...	W	5	S	58	W	22	N	89	W	7	N	116	...	...	...	98	W	15	N	118	Variable.
	May,	...	W	44	N	72	W	31	N	118	W	16	N	197	...	...	..	126	W	13	N	134	Calms frequent.
	June,	...	S	35	E	90	E	15	S	73	E	28	N	113	...	...	...	106	E	8	N	118	
	July,	...	S	40	E	74	E	27	S	58	E	32	N	103	...	...	...	54	E	12	S	106	
	August,	...	S	24	E	68		East.		94	N	23	E	117	...	...	...	58	E	5	N	102	
	September,	...	S	15	E	50	S	30	E	80	W	8	N	73	...	...	...	38	W	15	N	82	
	October,	...	S	23	E	36·8	W	2	S	...	W	10	N	61·8	...	...	...	26·4	W	23½	N	64·8	
	November,	...	S	38	E	21·2	N	44	W	44·7	W	9	N	25·3	...	...	...	...	W	12	N	51·7	

No. 204.

From—H. F. BLANFORD, ESQ., *Meteorological Reporter to Government of India.*

To—*The Secy. to Govt. of India, Department of Revenue, Agriculture and Commerce.*

I have the honor to return herewith the papers on the subject of wind-mills in the N.-W. Provinces, forwarded to me for remark, under your endorsement No. 27 of the 13th instant.

The question of the applicability of wind-mills for the purpose of irrigation must of course depend upon many circumstances, besides the existence of a sufficient motive power, but as this condition is fundamental, I may add a few remarks to those in the body of the report on this subject.

The mean diurnal movement of the wind at certain stations in the N.-W. Provinces has been given in the report from data supplied apparently by the Meteorological Reporter for the N.-W. Provinces. But the mean diurnal movement is an unfavorable criterion of the available wind-power, since it is well known that in most parts of India the wind movement is greater during the day, especially in the afternoon, than during the night. The hourly observations that are now recorded on certain days at certain stations in the N.-W. Provinces afford the means of showing this. I have selected those of Agra, and have tabulated the averages under each month, omitting those of the rains. The figures for the three months January to March, are the averages of four days' observations, those of the remaining months, of 8 days' observations.

The result shows that on an average there are several hours during the day in which the velocity of the wind at Agra is considerably above the requisite minimum deduced from Smeaton's estimate, although the mean of the twenty-four hours in certain months is below that minimum, and it may still, therefore, be a question whether at stations such as wind-mills might not be used with advantage.

Mean hourly movement of the wind at Agra.

Hours.	November.	December.	January.	February.	March.	April.	May.	June.
1	2·0	1·7	4·7	3·0	2·2	2·4	4·4	4·1
2	3·1	2·0	3·0	3·2	2·3	3·1	5·5	4·6
3	2·8	2·1	3·9	3·7	2·5	3·7	4·4	4·9
4	3·1	2·8	2·8	3·7	2·1	3·4	5·0	4·7
5	2·4	2·5	3·9	3·7	2·9	3·8	4·0	5·8
6	2·3	2·5	3·9	3·0	2·7	3·3	5·0	7·3
7	2·5	2·7	3·7	3·5	2·6	2·1	5·3	5·3
8	3·0	3·0	5·4	4·1	3·1	2·9	5·7	6·4
9	2·7	3·3	3·8	3·8	4·5	5·4	6·1	7·3
10	4·5	3·6	7·2	5·7	5·7	6·0	7·4	8·0
11	4·1	4·4	6·3	5·5	7·5	6·1	7·4	7·3
12	4·5	4·9	6·6	4·9	5·5	6·2	7·6	8·7
13	4·9	4·8	7·2	6·3	6·9	8·1	6·3	8·0
14	6·7	4·5	4·2	6·7	7·0	6·6	6·8	9·8
15	6·3	5·0	5·4	5·7	7·3	8·2	8·0	7·6
16	5·5	3·7	7·2	7·3	7·1	7·6	4·9	8·7
17	3·4	2·4	3·4	5·9	4·9	6·0	5·0	7·0
18	2·7	2·1	2·2	3·9	3·4	6·5	5·4	6·8
19	2·2	1·5	1·6	3·4	2·5	4·0	5·1	5·8
20	1·8	2·0	2·5	2·3	2·3	4·7	5·3	6·1
21	1·8	1·7	2·8	2·6	1·1	3·1	6·6	5·6
22	1·5	1·3	3·1	2·5	1·0	4·1	5·3	3·7
23	1·6	1·4	2·9	2·8	0·9	3·8	6·4	4·3
24	1·4	1·7	2·5	2·9	1·2	3·9	4·8	4·0
Total,	76·8	67·6	100·2	100·1	89·2	115·1	137·7	151·8
Mean,	3·2	2·81	4·17	4·17	3·71	4·8	5·73	6·32

Extract from Tracts on Hydraulics, edited by Thomas Tredgold, 1837, Part III. of Smeaton's Experimental Papers on the Power of Water and Wind to turn Mills.

On the Construction and effects of Wind-mill Sails.

In trying experiments on wind-mill sails, the wind itself is too uncertain to answer the purpose, we must, therefore, have recourse to an artificial wind.

This may be done two ways; either by causing the air to move against the machine, or the machine to move against the air. To cause the air to move against the machine, in a sufficient volume, with steadiness and the requisite velocity, is not easily put in practice: to carry the machine forward in a right line against the air would require a larger room than I could conveniently meet with. What I found most practicable, therefore, was to carry the axis, whereon the sails were to be fixed, progressively round in the circumference of a large circle. Upon this idea* a machine was constructed, as follows:—

Fig. 1 of Plate.

ABC is a pyramidical frame for supporting the moving parts.

DE is an upright axis, whereon is framed

FG, an arm for carrying the sails at a proper distance from the centre of the upright axis.

H is a barrel upon the upright axis, whereon is wound a cord; which, being drawn by the hand, gives a circular motion to the axis, and to the arm FG, and thereby carries the axis of the sails in the circumference of a circle, whose radius is DI, causing thereby the sails to strike the air, and turn round upon their own axis.

* Some years ago, Mr. Rouse, an ingenious gentleman of Harborough, in Leicestershire, set about trying experiments on the velocity of the wind, and force thereof upon plain surfaces and wind-mill sails; and much about the same time, Mr. Ellicott contrived a machine for the use of the late celebrated Mr. B. Robins, for trying the resistance of plain surfaces moving through the air. The machines of both these gentlemen were much alike, though at that time totally unacquainted with each other's inquiries. But it often happens that when two persons think justly upon the same subject, their experiments are alike. This machine was also built upon the same idea as the foregoing, but differed in having the hand for the first mover, with a pendulum for its regulator, instead of a weight, as in the former, which was certainly best for the purposes of measuring the impulse of the wind, or resistance of planes; but the latter is more applicable to experiments on wind-mill sails, because every change of position of the same sails will occasion their meeting the air with a different velocity, though urged by the same weight.

At L is fixed the end of a small line which, passing through the pullies MNO, terminates upon a small cylinder or barrel upon the axis of the sails, and, by winding thereon, raises

P, the scale, wherein the weights are placed for trying the power of the sails. This scale, moving up and down in the direction of the upright axis, receives no disturbance from the circular motion.

QR two parallel pillars standing upon the arm FG, for the purpose of supporting and keeping steady the scale P; which is kept from swinging by means of

ST, two small chains, which hang loosely round the two pillars.

W is a weight for bringing the centre of gravity of the moveable part of the machine into the centre of motion of the axis DE.

VX is a pendulum, composed of two balls of lead, which are moveable upon a wooden rod, and thereby can be so adjusted, as to vibrate in any time required. This pendulum hangs upon a cylindrical wire, whereon it vibrates, as on a rolling axis.

Y is a perforated table for supporting the axis of the pendulum.

Note.—The pendulum being so adjusted, as to make two vibrations in the time that the arm FG is intended to make one turn; the pendulum being set a vibrating, the experimenter pulls by the cord Z, with sufficient force to make each half revolution of the arm to correspond with each vibration, as equally as possible, during the number of vibrations that the experiment is intended to be continued. A little practice renders it easy to give motion thereto with all the regularity that is necessary.

Specimen of a set of Experiments.

	Radius of the sails, ...	21 inches.
	Length of ditto in the cloth, ...	18
	Breadth of ditto, ...	5·6
*	Angle at the extremity, ...	10 degrees.
	Ditto at the greatest inclination, ...	25
	20 turns of the sails raised the weight	11·3 inches.
	Velocity of the centre of the sails, in the circumference of the great circle, in a second, ...	6 feet.
	Continuance of the experiment, ...	52 seconds.

* In all the following experiments the angle of the sails is accounted from the plane of their motion; that is, when they stand at right angles to their axis, their angle is denoted 0°, this notation being agreeable to the language of practitioners, who call the angle so denoted the weather of the sail; which they denominate greater or less, according to the quantity of this angle.

No.		Weight in the scale. lbs.		Turns.		Product.
1	...	0	...	108	...	0
2	...	6	...	85	...	510
3	...	6½	...	81	...	526½
4	...	7	...	78	...	546
5	...	7½	...	73	...	547½ maximum.
6	...	8	...	65	...	520
7	...	9	...	0	...	0

N.B.—The weight of the scale and pulley was 3 oz.; and that 1 oz. suspended upon one of the radii, at 12½ inches from the centre of the axis, just overcame the friction; scale, and load of 7½ lbs.; and placed at 14$\frac{1}{2}\frac{9}{0}$ inches, overcame the same resistance with 9 lbs. in the scale.

Reduction of the preceding Specimen.

No. 5 being taken for the *maximum*, the weight in the scale was 7 lbs. 8 oz., which, with the weight of the scale and pulley, 3 oz., makes 7 lbs. 11 oz., equal to 123 oz.; this added to the friction of the machinery, the sum is the whole resistance.* The friction of the machinery is thus deduced; since 20 turns of the sails raised the weight 11·3 inches, with a double line, the radius of the cylinder will be ·18 of an inch; but, had the weight been raised by a single line, the radius of the cylinder being half the former, viz. ·09, the resistance would have been the same. We shall, therefore, have this analogy: as half the radius of the cylinder is to the length of the arm where the small weight was applied, so is the weight applied to the arm to a fourth weight, which is equivalent to the sum of the whole resistance together; that is, ·09 : 12·5 :: 1 oz. : 139 oz.; this exceeds 123 oz., the weight in the scale, by 16 oz. or 1 lb., which is equivalent to the friction; and which, added to the above weight of 7 lbs. 11 oz. makes 8 lbs. 11 oz. = 8·69 lbs. for the sum of the whole resistance; and this, multiplied by 73 turns, makes a product of 634, which may be called the representative of the *effect* produced.

In like manner, if the weight 9 lbs. which caused the sails to rest after being in motion, be augmented by the weight of the scale and its relative friction, it will become 10·37 lbs. The result of this specimen is set down in No. 12 of Table I., and the results of every other set of experiments therein contained were made and reduced in the same manner.

* The resistance of the air is not taken into the account of resistance, because it is inseparable from the application of the power.

TABLE I.

Containing nineteen sets of Experiments on Wind-mill Sails of various structures, positions, and quantities of surface.

The kind of sails made use of.	No.	Angle at the extremities.	Greatest angle.	Turns of the sails unloaded.	Turns of ditto at the maximum.	Load at the maximum.	Greatest load.	Product.	Quantity of surface.	Ratio of greatest velocity to the velocity at maximum.	Ratio of greatest load to the load at maximum.	Ratio of surface to the product.
		°	°			lbs.	lbs.	*	sq. in.			
Plain sails at an angle of 55° with the axis, ...	1	35	35	66	42	7·56	12·59	318	404	10:7	10:6	10:7·9
Plain sails weathered according to the common practice, ..	2	12	12	..	70	6·3	7·56	441	404	..	10:8·3	10:10·1
	3	15	15	105	69	6·72	8·12	464	404	10:6·6	10:8·3	10:10·15
	4	18	18	96	66	7·0	9·81	462	404	10:7	10:7·1	10:10·15
Weathered according to *Maclaurin's theorem*,	5	9	26½	..	66	7·0	..	462	404	..	..	10:11·4
	6	12	29½	..	70½	7·35	..	518	404	..	..	10:12·8
	7	15	32½	..	63½	8·3	..	527	404	..	..	10:13
Sails weathered in the *Dutch* manner, tried in various positions, ..	8	0	15	120	93	4·75	5·31	442	404	10:7·7	10:8·9	10:11
	9	3	18	120	79	7·0	8·12	553	404	10:6·6	10:8·6	10:13·7
	10	5	20	..	78	7·5	8·12	585	404	..	10:9·2	10:14·5
	11	7½	22½	113	77	8·3	9·81	639	404	10:6·8	10:8·5	10:15·8
	12	10	25	108	73	8·69	10·37	634	404	10:6·8	10:8·4	10:15·7
	13	12	27	100	66	8·41	10·94	580	404	10:6·6	10:7·7	10:14·4
Sails weathered in the *Dutch* manner, but *enlarged* towards the extremities, ..	14	7½	22½	123	75	10·65	12·59	799	505	10:6·1	10:8·5	10:15·8
	15	10	25	117	74	11·08	13·69	820	505	10:6·3	10:8·1	10:16·2
	16	12	27	114	66	12·09	14·23	799	505	10:5·8	10:8·4	10:15·8
	17	15	30	96	63	12·09	14·78	762	505	10:6·6	10:8·2	10:15·1
8 sails being *sectors of ellipses* in their best positions,	18	12	22	105	64½	16·42	27·87	1059	854	10:6·1	10:5·9	10:12·4
	19	12	22	99	64½	18·06	..	1165	1146	10:5·9	..	10:10·1
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.

OBSERVATIONS AND DEDUCTIONS FROM THE PRECEDING EXPERIMENTS.

I. *Concerning the best form and position of Wind-mill Sails.*

In Table I., No. 1, is contained the result of a set of experiments upon sails set at the angle which the celebrated Mons. Parent, and succeeding geometricians for many years, held to be the best; viz. those whose planes make an angle of 55°, nearly, with the axis; the complement whereof, or angle that the plane of the sail makes with the plane of their motion, will therefore be 35° as set down in columns 2 and 3. Now, if we multiply their number of turns by the weight they lifted, when working to the greatest advantage, as set down in columns 5 and 6, and compare this product (column 8) with the other products contained in the same column, instead of being the greatest, it turns out the least of all the rest. But if we set the angle of the same planes at somewhat less than half the former, or at any angle from 15° to 18°, as in Nos. 3 and 4, that is, from 72° to 75° with the axis, the product will be increased in the ratio of 31 : 45; and this is the angle most commonly made use of by practitioners, when the surfaces of the sails are planes.

If nothing more was intended than to determine the most efficacious angle to make a mill acquire motion from a state of rest, or to prevent it from passing into rest from a state of motion, we shall find the position of No. 1 the best; for if we consult column 7, which contains the least weights that would make the sails pass from motion to rest, we shall find that of No. 1 (relative to the quantity of cloth) the greatest of all. But if the sails are intended, with given dimensions, to produce the greatest effect possible in a given time, we must entirely reject those of No. 1, and *if we are confined to the use of planes, conform ourselves to some angle between Nos. 3 and 4, that is not less than 72°, or greater than 75°, with the axis.*

The late celebrated Mr. Maclaurin has judiciously distinguished between the action of the wind upon a sail at rest, and a sail in motion: and, in consequence, as the motion is more rapid near the extremities than towards the centre, that the angle of the different parts of the sail, as they recede from the centre, should be varied. For this purpose he has furnished us with the following theorem.* "Suppose the velocity of the wind to be represented by a, and the velocity of any given part of the sail to be denoted by c; then the effort of the wind upon that part of the sail will be greatest, when the tangent of the angle, in which the wind strikes it, is to radius as $\frac{3c}{2a} + \sqrt{2 + \frac{9c^2}{4a^2}}$ to 1." This theorem then assigns the law, by which the angle is to be varied according to the velocity of each part of the sail to the wind: but as it is left undetermined what velocity any one given part of the sail ought to have in respect to the wind, the angle that any one part of the sail ought to have, is left undetermined also; so that we are still at a loss for the proper *data* to apply the theorem. However, being willing to avail myself thereof, and considering that any angle from 15° to 18° was best suited to a plane,

* Maclaurin's Account of Sir Isaac Newton's Philosophical Discoveries, page 176, Art. 29.

and, of consequence, the best mean angle, I made the sail, at the middle distance between the centre and the extremity, to stand at an angle of 25° 41′ with the plane of the motion; in which case the velocity of that part of the sail, when loaded to a *maximum*, would be equal to that of the wind, or $c = a$. This being determined, the rest were inclined according to the theorem, as follows:—

			Angle with the axis.	Angle of weather.	
Parts of the radius from the centre,	$\frac{1}{6}$	$c = \frac{1}{3}a$	63° 26′	26° 34′	
	$\frac{2}{6}$	$c = \frac{2}{3}a$	69° 54′	20° 6′	
	$\frac{1}{2}$	$c = a$	74° 19′	15° 41′	middle.
	$\frac{2}{3}$	$c = 1\frac{1}{3}a$	77° 20′	12° 40′	
	$\frac{5}{6}$	$c = 1\frac{2}{3}a$	79° 27′	10° 33′	
	1	$c = 2a$	81° 0′	9° 0′	extremity.

The result hereof was according to No. 5, being nearly the same as the plane sails, in their best position: but being turned round in their sockets, so that every part of each sail stood at an angle of 3°, and afterwards at 6°, greater than before, that is, their extremities being moved from 9° to 12° and 15°, the products were advanced to 518 and 527 respectively. Now, from the small difference between those two products, we may conclude, that they were nearly in their best position, according to No. 7, or some angle between that and No. 6; but from these, as well as the plane sails and others, we may also conclude, that *a variation in the angle of a degree or two makes very little difference in the effect, when the angle is near upon the best.*

It is to be observed, that a sail inclined by the preceding rule will expose a convex surface to the wind: whereas the Dutch, and all our modern mill-builders, though they make the angle to diminish, in receding from the centre towards the extremity, yet constantly do it in such a manner, as that the surface of the sail may be concave towards the wind. In this manner the sails made use of in Nos. 8, 9, 10, 11, 12, and 13, were constructed; the middle of the sail making an angle with the extreme bar of 12°; and the greatest angle (which was about one-third of the radius from the centre) of 15° therewith. Those sails being tried in various positions, the best appears to be that of No. 11, where the extremities stood at an angle of 7½° with the plane of motion, the product being 639: greater than that of those made by the theorem in the ratio of 9 : 11, and double to that of No. 1; and this was the greatest product that could be procured without an augmentation of surface. Hence it appears, *that when the wind falls upon a concave surface, it is* *an advantage to the power of the whole, though every part, taken separately, should not be disposed to the best advantage.**

Having thus obtained the best position of the sails, or manner of weathering, as it is called by the workmen, the next point was to try what advantage could be made by an addition of surface upon the same radius. For this purpose the sails made use of had the same weather as those Nos. 8 to 13, with an addition to the leading side of each of a triangular cloth, whose height was equal to the height of the sail, and whose base was equal to half the breadth: of consequence, the increase of surface upon the whole was one-fourth part, or as 4 : 5. Those sails, by being turned round in their sockets, were tried in four different positions, specified in Nos. 14, 15, 16 and 17; from whence it appears, that the best was when every part of the sail made a greater angle, by 2½°, with the plane of the motion, than those without the addition, as appears by No. 15, the product being 820: this exceeds 639 more than in the ratio of 4 : 5, or that of the increase of cloth. Hence it appears, that *a broader sail requires a greater angle;* and *that when the sail is broader at the extremity than near the centre, this shape is more advantageous than that of a parallelogram.*†

Many have imagined, that the more sail the greater the advantage, and have, therefore, proposed to fill up the whole area: and by making each sail a sector of an ellipsis, according to Monsieur Parent, to intercept the whole cylinder of wind, and thereby to produce the greatest effect possible.

* By several trials in large, I have found the following angles to answer as well as any. The radius is supposed to be divided into 6 parts; and ⅙th, reckoning from the centre, is called 1, the extremity being denoted 6.

No.	Angle with the axis.	Angle with the plane of the motion.
1	72°	18°
2	71°	19°
3	72°	18° middle.
4	74°	16°
5	77½°	12½°
6	83°	7° extremity.

† The figure and proportion of the enlarged sails, which I have found best to answer in large, are represented in figure of *Plate*, where the extreme bar is ⅓rd of the radius (or whip, as it is called by the workmen), and is divided by the whip in the proportion of 3 to 5. The triangular, or leading sail, is covered with board, from the point downward, ⅓rd of its height, the rest with cloth as usual. The angles of weather in the preceding note are best for the enlarged sails also; for, in practice, it is found that the sails had better have too little than too much weather.

We have, therefore, proceeded to inquire how far the effect could be increased by a further enlargement of the surface, upon the same radius of which Nos. 18 and 19 are specimens. The surfaces, indeed, were not made planes, and set at an angle of 35°, as Parent proposed; because, from No. 1, we learn, that this position has nothing to do, when we intend them to work to the greatest advantage. We, therefore, gave them such an angle as the preceding experiments indicated for such sort of sails, viz. 12° at the extremity, and 22° for the greatest weather. By No. 18, we have the product 1059, greater than No. 15, in the ratio of 7 : 9; but then the augmentation of cloth is almost 7 : 12. By No. 19, we have the product 1165, that is greater than No. 15, as 7 : 10; but the augmentation of cloth is nearly as 7 : 16; consequently, had the same quantity of cloth as in No. 18, been disposed in a figure, similar to that of No. 15, instead of the product 1059, we should have had the product 1386; and in No. 19, instead of the product 1165, we should have had a product of 1860; as will be further made appear in the course of the following deductions. Hence it appears, that beyond a certain degree, the more the area is crowded with sail, the less effect is produced in proportion to the surface: and by pursuing the experiments still further, I found, that though in No. 19, the surface of all the sails together were not more than $\frac{7}{8}$ths of the circular area containing them, yet a further addition rather diminished than increased the effect. *So that when the whole cylinder of wind is intercepted, it does not then produce the greatest effect, for want of proper interstices to escape.*

It is certainly desirable that the sails of wind-mills should be as short as possible; but at the same time it is equally desirable, that the quantity of cloth should be the least that may be, to avoid damage by sudden squalls of wind. The best structure, therefore, for large mills is that where the quantity of cloth is the greatest, in a given circle, that can be: on this condition, that the effect holds out in proportion to the quantity of cloth; for otherwise the effect can be augmented in a given degree by a lesser increase of cloth upon a larger radius, than would be required if the cloth was increased upon the same radius. The most useful figure, therefore, for practice, is that of No. 9 or 10, as has been experienced upon several mills in large.

TABLE II.

Containing the result of six sets of Experiments made for determining the difference of effect according to the different velocity of the wind.

N.B.—The sails were of the same size and kind as those of Nos. 11, and 12, Table I. Continuance of the Experiment one minute.

No.	Angle at the extremity.	Velocity of the wind in a second.	Turns of the sails unloaded.	Turns of the sails at maximum.	Load at the maximum.	Greatest Load.	Product.	Maximum load for the half velocity.	Turns of the sails therewith.	Product of lesser load and greater velocity.	Ratio of the two products.	Ratio of the greatest velocity to the velocity at a maximum.	Ratio of the greatest load to the load at a maximum.
	°	ft. in.			lbs.	lbs.							
1	5	4 4½	96	66	4·47	5·37	295	..	..	..	..	10:6·9	10:8·3
2	5	8 9	207	122	16·42	18·06	2003	4·47	180	805	10:27·3	10:5·9	10:9·1
3	7½	4 4½	..	65	4·62	..	300	..	..	..	..	..	..
4	7½	8 9	..	130	17·52	..	2278	4·62	180	832	10:27·8	..	..
5	10	4 4½	91	61	5·03	5·87	307	..	..	..	..	10:6·7	10:8·5
6	10	8 9	178	110	18·61	21·34	2047	5·03	158	795	10:26	10:6·2	10:8·7
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.

II.—*Concerning the ratio between the velocity of wind-mill sails unloaded, and their velocity when loaded to a maximum.*

Those ratios, as they turned out in experiments upon different kinds of sails, and with different inclinations (the velocity of the wind being the same), are contained in column 10 of Table I., where the extremes differ from the ratio of 10 : 7·7 to that of 10 : 5·8; but *the most general ratio of the whole will be nearly as* 3 : 2. This ratio also agrees sufficiently near with experiments where the velocity of the wind was different, as in those contained in Table II., column 13, in which the ratios differ from 10 : 6·9 to that of 10 : 5·9. However, it appears, in general, that where the power is greater, whether by an enlargement of surface, or a greater velocity of the wind, that the second term of the ratio is less.

III.—*Concerning the ratio between the greatest load that the sails will bear without stopping, or what is nearly the same thing, between the least load that will stop the sails, and the load at the maximum.*

Those ratios for different kinds of sails and inclinations, are collected in column 11, Table I., where the extremes differ from the ratio of 10 : 6 to that of 10 : 9·2; but taking in those sets of experiments only, where the sails respectively answered best, *the ratios will be confined between* *that of* 10 : 8 *and of* 10 : 9; *and at a medium about* 10 : 8·3 *or* 6 : 5. This ratio also agrees nearly with those in column 14 of Table II. However it appears, upon the whole, that in those instances, where the angle of the sails or quantity of cloth were greatest, that the second term of the ratio was less.

IV.—*Concerning the effects of sails, according to the different velocity of the wind.*

Maxim 1.—*The velocity of wind-mill sails, whether unloaded or loaded, so as to produce a maximum, is nearly as the velocity of the wind, their shape and position being the same.*

This appears by comparing together the respective numbers of columns 4 and 5, Table II., wherein those of Nos. 2, 4, and 6, ought to be double of Nos. 1, 3, and 5: but as the deviation is nowhere greater than what may be imputed to the inaccuracy of the experiments themselves, and holds good exactly in Nos. 3 and 4; which sets were deduced from the medium of a number of experiments, carefully repeated the same day, and, on that account, are most to be depended upon, we may therefore conclude the maxim true.

Maxim 2.—*The load at the maximum is nearly, but somewhat less than, as the square of the velocity of the wind, the shape and position of the sails being the same.*

This appears by comparing together the numbers in column 6, Table II., wherein those of Nos. 2, 4, and 6 (as the velocity is double) ought to be quadruple of those Nos. 1, 3, and 5; instead of which they fall short, No. 2 by $\frac{1}{14}$, No. 4 by $\frac{1}{19}$, and No. 6 by $\frac{1}{18}$ part of the whole. The greatest of those deviations is not more considerable than might be imputed to the unavoidable errors in making the experiments: but as those experiments, as well as those of the greatest load, all deviate the same way, and also coincide with some experiments communicated to me by Mr. Rouse, upon the resistance of planes, I am led to suppose a small deviation, whereby the load falls short of the squares of the velocity; and since the experiments, Nos. 3 and 4, are most to be depended upon, we must conclude, that when the velocity is double, the load falls short of its due proportion by $\frac{1}{19}$, or, for the sake of a round number, by about $\frac{1}{20}$ part of the whole.

Maxim 3.—*The effects of the same sail at a maximum are nearly, but somewhat less than, as the cubes of the velocity of the wind.*

It has already been proved, Maxim 1st, that the velocity of sails at the *maximum*, is nearly as the velocity of the wind; and by Maxim 2nd, that the load at the *maximum* is nearly as the square of the same velocity: if those two *maxima* would hold precisely, it would be a consequence that the effect would be in a triplicate ratio thereof; how this agrees with experiment will appear by comparing together the products in column 8 of Table II., wherein those of Nos. 2, 4, and 6 (the velocity of the wind being double), ought to be octuple of those of Nos. 1, 3, and 5, instead of which they fall short, No. 2 by $\frac{1}{7}$, No. 4 by $\frac{1}{20}$, and No. 6 by $\frac{1}{6}$ part of the whole. Now, if we rely on Nos. 3 and 4, as the turns of the sails are as the velocity of the wind; and since the load of the maximum falls short of the square of the velocity by about $\frac{1}{20}$ part of the whole: the product made by the multiplication of the turns into the load, must also fall short of the triplicate ratio by about $\frac{1}{20}$ part of the whole product.

Maxim 4.—*The load of the same sails at the maximum is nearly as the squares, and their effect as the cubes of their number of turns in a given time.*

This maxim may be esteemed a consequence of the three preceding; for if the turns of the sails are as the velocity of the wind, whatever quantities are in any given ratio of the velocity of the wind, will be in the same given ratio of the turns of the sails: and, therefore, if the load at the *maximum* is as the square, or the effect as the cube of the velocity of the wind, wanting $\frac{1}{20}$ part when the velocity is double; the load at the *maximum* will also be as the square, and the effect as the cube of the number of turns of the sails in a given time, wanting, in like manner, $\frac{1}{20}$ part when the number of turns are double in the same time. In the present case, if we compare the loads at the *maximum*, column 6, with the squares of the number of turns, column 5 of Nos. 1 and 2, 5 and 6, or the products of the same numbers column 8, with the cubes of the number of turns, column 5, instead of falling short, as Nos. 3 and 4, they exceed those ratios; but, as the sets of experiments, Nos. 1 and 2 of 5 and 6, are not to be esteemed of equal authority with those of Nos. 3 and 4, we must not rely upon them further than to observe that *in comparing the gross effects of large machines, the direct proportion of the* *squares and cubes respectively, will hold as near as the effects themselves can be observed;* and, therefore, be sufficient for practical estimation without any allowance.

Maxim 5.—*When sails are loaded, so as to produce a maximum at a given velocity, and the velocity of the wind increases, the load continuing the same:* 1st, *The increase of effect, when the increase of the velocity of the wind is small, will be nearly as the squares of those velocities;* 2ndly, *When the velocity of the wind is double, the effects will be nearly as* 10 : 27½; *But* 3rdly, *When the velocities compared, are more than double of that where the given load produces a maximum, the effects increase nearly in a simple ratio of the velocity of the wind.*

It has already been proved, Maxim 1st and 2nd, that when the velocity of the wind is increased, the turns of the sails will increase in the same proportion, even when opposed by a load as the square of the velocity; and therefore, if wanting, the opposition of an increase of load, as the square of the velocity, the turns of the sails will again be increased in a simple ratio of the velocity of the wind, on that account also; that is, the load continuing the same, the turns of the sails in a given time will be as the square of the velocity of the wind; and the effect, being, in this case, as the turns of the sails, will be as the square of the velocity of the wind also; but this must be understood only of the first increments of the velocity of the wind: for,

2ndly, As the sails will never acquire above a given velocity in relation to the wind, though the load was diminished to nothing, when the load continues the same, the more the velocity of the wind increases (though the effect will continue to increase) yet the more it will fall short of the square of the velocity of the wind; so that when the velocity of the wind is double, the increase of effect, instead of being as 1 : 4, according to the squares, it turns out as 10 : 27½, as thus appears. In Table II., column 9, the loads of Nos. 2, 4, and 6, are the same as the maximum load in column 6 of Nos. 1, 3, and 5. The number of turns of the sails with those loads, when the velocity of the wind is double, are set down in column 10, and the products of their multiplication in column 11: those being compared with the products of Nos. 1, 3, and 5, column 8, furnish the ratios set down in column 12, which, at a medium (due regard being had to Nos. 3 and 4) will be nearly as 10 : 27½.

3rdly, The load continuing the same, grows more and more inconsiderable, respecting the power of the wind as it increases in velocity; so that the turns of the sails grow nearer and nearer a coincidence with their turns unloaded; that is, nearer and nearer to the simple ratio of the velocity of the wind. When the velocity of the wind is double, the turns of the sails, when loaded to a *maximum*, will be double also; but, *unloaded*, will be more than triple, by deduction 2nd: and, therefore, the product could not have increased beyond the ratio of 10 : 30 (instead of 10 : 27½), even supposing the sails not to have been retarded at all by carrying the *maximum* load for half the velocity. Hence we see, that when the velocity of the wind exceeds the double of that, where a constant load produces a *maximum*, that the increase of effect, which follows the increase of the velocity of the sails, will be nearly as the velocity of the wind, and ultimately in that ratio precisely. Hence, also, we see that wind-mills, such as the different species for raising water for drainage, &c., lose much of their full effect, when acting against one invariable opposition.

V.—*Concerning the effects of sails of different magnitudes, the structure and position being similar, and the velocity of the wind the same.*

Maxim 6.—*In sails of a similar figure and position, the number of turns in a given time will be reciprocally as the radius or length of the sail.*

The extreme bar having the same inclination to the plane of its motion, and to the wind: its velocity at a *maximum* will always be in a given ratio to the velocity of the wind; and, therefore, whatever be the radius, the absolute velocity of the extremity of the sail will be the same; and this will hold good respecting any other bar, whose inclination is the same, at a proportionable distance from the centre; it therefore follows, that the extremity of all similar sails, with the same wind, will have the same absolute velocity; and, therefore, take a space of time to perform one revolution in proportion to the radius; or, which is the same thing, the number of revolutions in the same given time, will be reciprocally as the length of the sail.

Maxim 7.—*The load at a maximum that sails of a similar figure and position will overcome, at a given distance from the centre of motion, will be as the cube of the radius.*

Geometry informs us, that in similar figures the surfaces are as the squares of their similar sides; of consequence the quantity of cloth will be as the square of the radius: also, in similar figures and positions, the impulse of the wind upon every similar section of the cloth, will be in proportion to the surface of that section; and, consequently, the impulse of the wind upon the whole, will be as the surface of the whole: but as the distance of every similar section, from the centre of motion, will be as the radius; the distance of the centre of power of the whole, from the centre of motion, will be as the radius also: that is, the lever by which the power acts will be as the radius: as, therefore, the impulse of the wind, respecting the quantity of cloth, is as the square of the radius, and the lever by which it acts, as the radius simply; it follows, that the load which the sails will overcome, at a given distance from the centre, will be as the cube of the radius.

Maxim 8.—*The effect of sails of similar figure and position, are as the square of the radius.*

By Maxim 6, it is proved, that the number of revolutions made in a given time, are as the radius inversely. Under Maxim 7, it appears, that the length of the lever, by which the power acts, is as the radius directly; therefore these equal and opposite ratios destroy one another: but, as in similar figures the quantity of cloth is as the square of the radius, and the action of the wind is in proportion to the quantity of cloth, as also appears under Maxim 7, it follows that the effect is as the square of the radius.

Corol. 1.—Hence it follows, that augmenting the length of the sail, without augmenting the quantity of cloth, does not increase the power; because what is gained by the length of the lever, is lost by the slowness of the rotation.

Corol. 2.—If the sails are increased in length, the breadth remaining the same, the effect will be as the radius.

VI.—*Concerning the velocity of the extremities of wind-mill sails, in respect to the velocity of the wind.*

Maxim 9.—*The velocity of the extremities of* Dutch *sails, as well as of the enlarged sails, in all their usual positions when unloaded, or even loaded, to a maximum, is considerably quicker than the velocity of the wind.*

The *Dutch* sails unloaded, as in Table I., No. 8, made 120 revolutions in 52 seconds: the diameter of the sails being 3 feet 6 inches, the velocity of their extremities will be 25·4 feet in a second; but the velocity of the wind producing it, being 6 feet in the same time, we shall have

6 : 25·4 :: 1 : 4·2; in this case, therefore, the velocity of their extremities was 4·2 times greater than that of the wind. In like manner, the relative velocity of the wind, to the extremities of the same sails, when loaded to a *maximum*, making then 93 turns in 52 seconds, will be found to be as 1 : 3·3; or 3·3 times quicker than that of the wind.

The following table contains six examples of *Dutch* sails, and four examples of the enlarged sails, in different positions, but with the constant velocity of the wind of 6 feet in a second, from Table I.; and also six examples of *Dutch* sails in different positions, with different velocities of the wind from Table II.

Table III.

Containing the ratio of the velocity of the extremities of wind-mill sails to the velocity of the wind.

No.	No. of Table I. and II.	Angle at the extremity.	Velocity of the wind in a second.	Ratio of the velocity of the wind and extremities of the sails. Unloaded.	Loaded.	
1	8	0°	6 0	1 : 4·2	1 : 3·3	From Table I.
2	9	3	6 0	1 : 4·2	1 : 2·8	
3	10	5	6 0	...	1 : 2·75	
4	11	7½	6 0	1 : 4	1 : 2·7	
5	12	10	6 0	1 : 3·8	1 : 2·6	
6	13	12	6 0	1 : 3·5	1 : 2·3	
7	14	7½	6 0	1 : 4·3	1 : 2·6	
8	15	10	6 0	1 : 4·1	1 : 2·6	
9	16	12	6 0	1 : 4	1 : 2·3	
10	17	15	6 0	1 : 3·35	1 : 2·2	
11	1	5	4 4½	1 : 4	1 : 2·8	From Table II.
12	2	5	8 9	1 : 4·3	1 : 2·6	
13	3	7½	4 4½	...	1 : 2·8	
14	4	7½	8 9	...	1 : 2·7	
15	5	10	4 4½	1 : 3·8	1 : 2·6	
16	6	10	8 9	1 : 3·4	1 : 2·3	
1.	2.	3.	4.	5.	6.	

It appears from the preceding collection of examples, that when extremities of the *Dutch* sails are parallel to the plane of motion; or at right angles to the wind and to the axis, as they are made according to the common practice in *England*, that their velocity, unloaded, is above four times, and loaded to a *maximum*, above three times greater than that of the wind: but that when the Dutch sails, or enlarged sails, are in their best positions, their velocity unloaded is four times, and loaded to a *maximum*, at a medium, the Dutch sails are 2·7, and the enlarged sails 2·6 times greater than the velocity of the wind. Hence we are furnished with a method of knowing the velocity of the wind, from observing the velocity of the wind-mill sails: for, knowing the radius and the number of turns in a minute, we shall have the velocity of the extremities; which, divided by the following divisors, will give the velocity of the wind.

Dutch sails in their common position, ...	unloaded	4·2
	loaded	3·3
Dutch sails in their best position, ...	unloaded	4·0
	loaded	2·7
Enlarged sails in their best position, ...	unloaded	4·0
	loaded	2·6

From the above divisors there arises the following compendiums: supposing the radius to be 30 feet, which is the most usual length in this country, and the mill to be loaded to a *maximum*, as is usually the case with corn-mills; for every 3 *turns in a minute, of the Dutch sails in their common position, the wind will move at the rate of two miles an hour;* for every 5 *turns in a minute of the Dutch sails in their best position, the wind moves four miles an hour;* and for every 6 *turns in a minute, of the enlarged sails in their best position, the wind will move five miles an hour.*

The following table, which was communicated to me by my friend, Mr. Rouse, and which appears to have been constructed with great care, from a considerable number of facts and experiments, and which, having relation to the subject of this article, I here insert it as he sent it to me; but, at the same time, must observe, that the evidence for those numbers where the velocity of the wind exceeds 50 miles in an hour, does not seem of equal authority with those of 50 miles an hour and under. It is also to be observed, that the numbers in column 3, are calculated according to the square of the velocity of the wind, which, in moderate velocities, from what has been before observed, will hold very nearly.

Table IV.

Containing the velocity and force of wind, according to their common appellations.

Velocity of the wind. Miles in one hour.	Velocity of the wind. Feet in one second.	Perpendicular force on one foot area in pounds avoirdupois.	Common appellations of the force of the winds.
1	1·47	·005	Hardly perceptible.
2	2·93	·020	Just perceptible.
3	4·40	·044	
4	5·87	·079	Gentle pleasant wind.
5	7·33	·123	
10	14·67	·492	Pleasant brisk gale.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36·67	3·075	
30	44·01	4·429	High winds.
35	51·34	6·027	
40	58·68	7·873	Very high.
45	66·01	9·963	
50	73·35	12·300	A storm or tempest.
60	88·02	17·715	A great storm.
80	117·36	31·490	A hurricane.
100	146·70	49·200	A hurricane that tears up trees, carries buildings before it, &c.
1.	2.	3.	

VII.—*Concerning the absolute effect produced by a given velocity of the wind upon sails of a given magnitude and construction.*

It has been observed by practitioners, that, in mills with Dutch sails in the common position, when they make about 13 turns in a minute, they then work at a mean rate: that is, by the compendiums in the last article, when the velocity of the wind is $8\frac{2}{3}$ miles an hour, or $12\frac{2}{3}$ feet in a second; which, in common phrase, would be called a *fresh gale.*

The experiments set down in Table II., No. 4, were tried with a wind, whose velocity was $8\frac{3}{4}$ feet in a second; consequently, had those experiments been tried with a wind whose velocity was $12\frac{2}{3}$ feet in a second, the effect, by Maxim 3rd, would have been 3 times greater: because the cube of $12\frac{2}{3}$ is 3 times greater than that of $8\frac{3}{4}$.

From Table II., No. 4, we find that the sails, when the velocity of the wind was 8¾ feet in a second, made 130 revolutions in a minute, with a load of 17·52 lbs. From the measures of the machine preceding the specimen of a set of experiments, we find, that twenty revolutions of the sails raised the scale and weight 11·3 inches: 130 revolutions will therefore raise the scale 73·45 inches, which, multiplied by 17·52 lbs., makes a product of 1287, for the effect of the Dutch sails in their best position; that is, when the velocity of the wind is 8¾ feet in a second: this product, therefore, multiplied by three, will give 3861 for the effect of the same sails, when the velocity of the wind is 12⅔ feet in a second.

Desaguliers makes the utmost power of a man, when working so as to be able to hold it for some hours, to be equal to that of raising a hogshead of water 10 feet high in a minute. Now, a hogshead, consisting of 63 ale gallons, being reduced into pounds avoirdupois, and the height into inches; the product made by multiplying those two numbers will be 76,800; which is 19 times greater than the product of the sails last mentioned, at 12½ feet in a second: therefore, by Maxim 8th, if we multiply the square root of 19, that is 4·46, by 21 inches, the length of the sail producing the effect 3861, we shall have 93·66 inches, or 7 feet 9⅔ inches for the radius of a Dutch sail in its best position, whose mean power shall be equal to that of a man: but if they are in their common position, their length must be increased in the ratio of the square root of 442 to that of 639, as thus appears:

The ratio of the *maximum* products of Nos. 8 and 11, Table I., are as 442 : 639: but, by Maxim 8, the effects of sails of different radii are as the square of the radii; consequently, the square roots of the products or effects, are as the radii simply: and, therefore, as the square root of 442 is to that of 639, so is 93·66 to 112·66; or 9 feet 4⅔ inches.

If the sails are of the enlarged kind, then, from Table I., Nos. 11 and 15, we shall have the square root of 820 to that of 639 :: 93·66 : 82·8 inches, or 6 feet 10¾ inches: so that, in round numbers, we shall have the radius of a sail, of a similar figure to their respective models, whose mean power shall be equal to that of a man.

The Dutch sails in their common position,	...	9¼ feet.
The Dutch sails in their best position, ...	...	8 „
The enlarged sails in their best position, ...	...	7 „

Suppose, now, the radius of a sail to be 30 feet, and to be constructed upon the model of the enlarged sails, No. 14 or 15, Table I., dividing

30 by 7, we shall have 4·28, the square of which is 18·3; and this, according to Maxim 7, will be the relative power of a sail of 30 feet to one of 7 feet; that is, when working at a mean rate, the 30 feet sail will be equal to the power of 18·3 men, or of 3⅗ horses; reckoning 5 men to a horse: whereas the effect of the common Dutch sails, of the same length, being less in the proportion of 820 : 442, will be scarce equal to the power of 10 men, or of 2 horses.

That these computations are not merely speculative, but will nearly hold good when applied to works in large, I have had an opportunity of verifying: for, in a mill with the enlarged sails of 30 feet, applied to the crushing of rape-seed, by means of two runners upon the edge, for making oil, I observed, that when the sails made 11 turns in a minute, in which case the velocity of the wind was about 13 feet in a second, according to Article VI., that the runners then made 7 turns in a minute: whereas 2 horses, applied to the same two runners, scarcely worked them at the rate of 3½ turns in the same time. Lastly, with regard to the real superiority of the enlarged sails above the Dutch sails as commonly made, it has sufficiently appeared, not only in those cases where they have been applied to new mills, but where they have been substituted in the place of the others.

VIII.—*Concerning horizontal Wind-mills and Water-wheels with oblique vanes.*

Observations upon the effects of common wind-mills, with oblique vanes, have led many to imagine that, could the vanes be brought to receive the direct impulse, like a ship sailing before the wind, it would be a very great improvement in point of power; while others, attending to the extraordinary and even unexpected effects of oblique vanes, have been led to imagine that oblique vanes applied to water-mills, would as much exceed the common water-wheels, as the vertical wind-mills are found to have exceeded all attempts towards a horizontal one. Both these notions, but especially the first, have so plausible an appearance, that of late years there have seldom been wanting those who have assiduously employed themselves to bring to bear designs of this kind; it may not, therefore, be unacceptable to endeavour to set this matter in a clear light.

Fig. 2 of Plate. Let AB be the section of a plane, upon which let the wind blow in the direction CD, with such a velocity as to describe a given space BE, in a given time (suppose one second), and let AB be moved parallel to itself, in the direction CD. Now, if the plane AB moves with the same velocity as the wind; that is, if the point B moves through the space BE in the same time that a particle of air would move through the same space; it is plain that, in this case, there can be no pressure or impulse of the wind upon the plane: but if the plane moves slower than the wind, in the same direction, so that the point B may move to F, while a particle of air, setting out from B at the same instant, would move to E, then BF will express the velocity of the plane; and the relative velocity of the wind and plane will be expressed by the line FE. Let the ratio of FE to BE be given (suppose 2 : 3), let the line AB represent the impulse of the wind upon the plane AB, when acting with its whole velocity BE; but, when acting with its relative velocity FE, let its impulse be denoted by some aliquot part of AB, as, for instance, $\frac{4}{9}$ AB: then will $\frac{4}{9}$ of the parallelogram AF represent the mechanical power of the plane; that is, $\frac{4}{9}$ AB $\times$ $\frac{1}{3}$ BE.

2ndly. Let IN be the section of a plane, inclined in such a manner, that the base IK of the rectangled triangle IKN may be equal to AB; and the perpendicular NK = BE; let the plane IN be struck by the wind, in the direction LM, perpendicular to IK; then, according to the known rules of oblique forces, the impulse of the wind upon the plane IN tending to move it according to the direction LM, or NK, will be denoted by the base IK; and that part of the impulse, tending to move it according to the direction IK, will be expressed by the perpendicular NK. Let the plane IN be moveable in the direction of IK only; that is, the point I in the direction of IK, and the point N in the direction NQ, parallel thereto. Now, it is evident, that if the point I moves through the line IK, while a particle of air, setting forwards at the same time from the point N, moves through the line NK, they will both arrive at the point K at the same time; and, consequently, in this case also, there can be no pressure or impulse of the particle of the air upon the plane IN. Now, let IO be to IK as BF to BE; and let the plane IN move at such a rate, that the point I may arrive at O, and acquire the position IQ, in the same time that a particle of wind would move through the space NK: as OQ is parallel to IN; (by the properties of similar triangles) it will cut NK in the point P, in such a manner, that NP = BF, and PK = FE; hence, it appears that the plane IN, by acquiring the position OQ, withdraws itself from the action of the wind, by the same space NP, that the plane AB does by acquiring the position FG; and, consequently, from the equality of PK to FE, the relative impulse of the wind PK, upon the plane OQ, will be equal to the relative impulse of the wind FE upon the plane FG: and since the impulse of the wind upon AB, with the relative velocity FE, in the direction BE, is represented by $\frac{4}{9}$ AB; the relative impulse of the wind upon the plane IN, in the direction NK, will, in like manner, be represented by $\frac{4}{9}$ IK; and the impulse of the wind upon the plane IN, with the relative velocity PK, in the direction IK, will be represented by $\frac{4}{9}$ NK; and, consequently, the mechanical power of the plane IN, in the direction IK, will be $\frac{4}{9}$ the parallelogram IQ: that is $\frac{1}{3}$ IK × $\frac{4}{9}$ NK: that is, from the equality of IK = AB and NK = BE, we shall have $\frac{4}{9}$ IQ = $\frac{1}{3}$ AB × $\frac{4}{9}$ BE = $\frac{4}{9}$ AB × $\frac{1}{3}$ BE = $\frac{4}{9}$ of the area of the parallelogram AF. Hence we deduce this

General Proposition.

That all planes, however situated, that intercept the same section of the wind, and having the same relative velocity, in regard to the wind, when reduced into the same direction, have equal powers to produce mechanical effects.

For what is lost by the obliquity of the impulse is gained by the velocity of the motion.

Hence, it appears that an oblique sail is under no disadvantage in respect of power, compared with a direct one; except what arises from a diminution of its breadth, in respect to the section of the wind: the breadth IN being by obliquity reduced to IK.

The disadvantage of horizontal wind-mills, therefore, does not consist in this, that each sail, when directly opposed to the wind, is capable of a less power than an oblique one of the same dimensions; but that, in a horizontal wind-mill, little more than one sail can be acting at once; whereas, in the common wind-mill all the four act together: and therefore, supposing each vane of a horizontal wind-mill, of the same dimensions as each vane of the vertical, it is manifest the power of a vertical mill with four sails will be four times greater than the power of the horizontal one, let its number of vanes be what it will: this disadvantage arises from the nature of the thing: but if we consider the further disadvantage, that arises from the difficulty of getting the sails back again against the wind, &c., we need not wonder if this kind of mill is, in reality, found to have not above $\frac{1}{8}$ or $\frac{1}{10}$ of the power of the common sort; as has appeared in some attempts of this kind.

In like manner, as little improvement is to be expected from water-mills with oblique vanes; for the power of the same section of a stream of water is not greater when acting upon an oblique vane than when acting upon a direct one: and any advantage that can be made by intercepting a greater section, which sometimes may be done in the case of an open river, will be counterbalanced by the superior resistance that such vanes would meet with by moving at right angles to the current: whereas the common floats always move with the water nearly in the same direction.

Here it may reasonably be asked, that since our geometrical demonstration is general, and proves that one angle of obliquity is as good as another, why in our experiments it appears that there is a certain angle which is to be preferred to all the rest? It is to be observed, that if the breadth of the sail IN is given, the greater the angle KIN, and the less will be the base IK: that is, the section of wind intersected, will be less: on the other hand, the more acute the angle KIN, the less will be the perpendicular KN: that is, the impulse of the wind, in the direction IK, being less, and the velocity of the sail greater; the resistance of the medium will be greater also. Hence, therefore, as there is a diminution of the section of the wind intercepted on one hand, and an increase of resistance on the other, there is some angle where the disadvantage arising from these causes, upon the whole, is the least of all; but as the disadvantage arising from resistance is more of a physical than geometrical consideration, the true angle will best be assigned by experiment.

Scholium.

In trying the experiments contained in Tables I. and II., the different specific gravity of the air, which is undoubtedly different at different times, will cause a difference in the load, proportional to the difference of its specific gravity, though its velocity remains the same; and a variation of specific gravity may arise not only from a variation of the weight of the whole column, but also by the difference of heat of the air concerned in the experiment, and possibly of other causes; yet the irregularities that might arise from a difference of specific gravity were thought to be too small to be perceivable, till after the principal experiments were made, and their effects compared; from which, as well as succeeding experiments, those variations were found to be capable of producing a sensible, though no very considerable, effect; however, as all the experiments were tried in the summer season, in the day time, and under cover, we may suppose that the principal source of error would arise from the different weight of the column of the atmosphere at different times; but as this seldom varies above $\frac{1}{15}$ part of the whole, we may conclude, that though many of the irregularities contained in the experiments referred to in the foregoing essay might arise from this cause, yet, as all the principal conclusions are drawn from the medium of a considerable number, many whereof were made at different times, it is presumed that they will nearly agree with the truth, and be altogether sufficient for regulating the practical construction of those kind of machines, for which use they were principally intended.

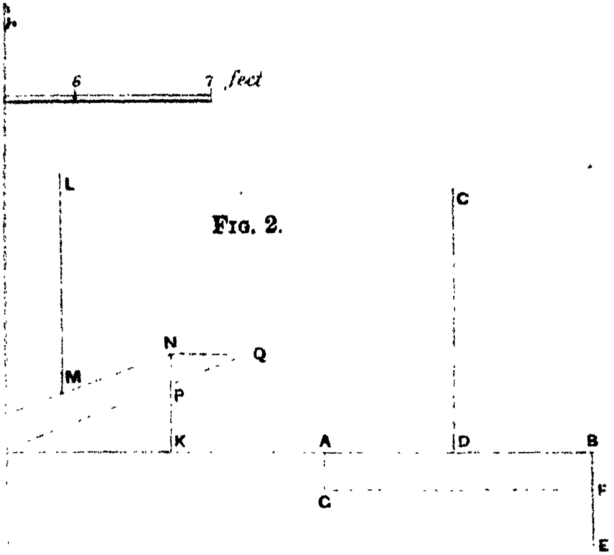
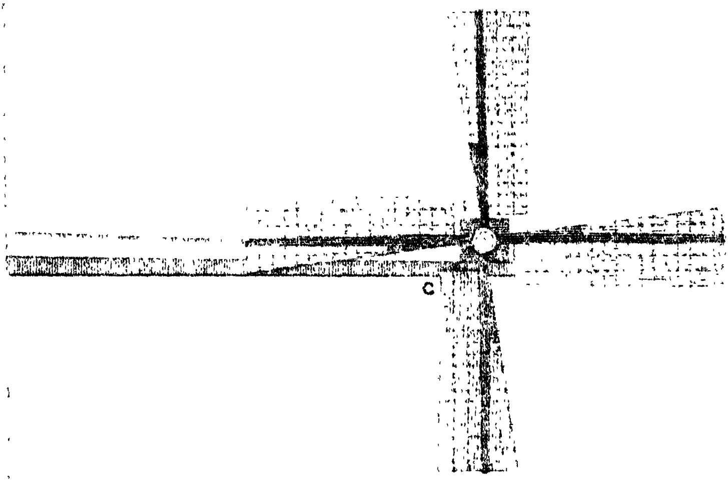


Fig. 2.



No. CCCVII.

WATER SUPPLY FOR THE CITY OF JEYPORE.

[*Vide* Plates I.—III.]

BY MAJOR S. S. JACOB, B.S.C., *Exec. Engineer, Jeypore State.*

THE town of Jeypore is situated in a small valley surrounded by hills on the north, the north-west and the east; and is open only towards the west and south-west. The city walls stretch from hill to hill across the open face and enclose the city.

The city was founded A.D. 1718 by Maharajah Sewaie Jey Singh, whose Encyclopædia of Hindoo Theology, Mathematical Tables, and Observatories at Delhi, Benares, Oojein and Jeypore prove him to have been a man of great attainments. During the greater portion of his life, however, he was engaged in active warfare, and it was no doubt the strong defensible position, which the surrounding hills give the present city of Jeypore, as well as its proximity to Amber, the old capital of the State, which induced Maharajah Sewaie Jey Singh to found the modern city where it now is.

There is a small stream called the Amani Shah which rises in the hills north of the city, and flows past about 1½ miles west of the city. The soil through which it passes is soft sand. From traces of an excavated channel, which still exist, it is evident that formerly the bed of this stream was about 25 feet below the surface, and that it was at one time diverted towards the city, probably by an earthen bund annually constructed, as is done every year on this stream a few miles further down, where the banks are sufficiently low to admit of the water being taken away.

This perhaps may have influenced Maharajah Sewaie Jey Singh also, as to the site of his new city; be this as it may, at present there are only 49 wells of sweet water in the city out of about 827, and the Amani Shah now runs between banks of sand 50 feet deep, which make it impossible to divert the water towards the city, as we imagine it used to be diverted formerly.

It is not probable that such a man as Maharajah Sewaie Jey Singh would have founded Jeypore in such a position had any difficulties regarding water supply then existed.

Tradition, however, states that some attempt was once made about Jey Singh's time to bring water from the river Bandi, which runs about 20 miles west of Jeypore, and the remains of a masonry dam in the bed of this river, and traces of a bank and excavation here and there across the country, tend to confirm these reports; the attempt, however, appears to have been unsuccessful.

It is possible that failing to bring any water across the Amani Shah, an attempt was made to divert it into a jhil about 6 miles north of Jeypore, known as Bhao Sagar or Akhera Talao. An excavated channel for about a mile in length and 50 feet wide shows some such attempt was once made. We have taken advantage of this to increase the water supply to Bhao Sagar, by connecting this cut with the hills adjacent, this, however, is no part of the city water supply, and is purely for irrigation.

Another attempt was made to supply the city about 35 years ago with water from the Amani Shah. A large masonry dam (remains shown in *Plate* I.) about 60 feet high and 300 feet long with massive apron in steps, was built across the nallah to impound the floods, and a masonry duct in section 3′ × 2′ provided with upright masonry air shafts at every 400 feet was constructed for a length of 3 miles to the city, where open reservoirs in the city squares were made to receive the water.

The difference of level between the dam and the city was so little, that it was necessary to take off the duct at the top of the dam, and owing to high ground between the dam and the city, it was necessary to make the duct take a wide detour to the south before it reached the city. Even then the ducts entered the service reservoirs at the bottom.

The dam was founded on wells, and appears to have been built of first rate masonry. Bathing ghats were built on the banks of the nallah at each end of the dam on the up-stream side, and wells for irrigation were made along the banks of what, it was intended should be, a grand storage reservoir.

It took some seasons to fill up, but eventually it is stated the water did reach the level of the duct to the city, though only for a short time.

Water was, however, soon seen to spurt out at one side of the dam, the jet became a torrent, the west half of the dam was carried away, and by evening there was nothing left, after an expenditure of about 4½ lakhs rupees, but a gigantic ruin and an empty nallah, the bed of which was many feet below what it was before the dam was made.

The Maharajah himself, then a minor, was an eye-witness of the catastrophe, and describes it as "the most grand and most expensive *tamasha*" he has ever seen.

The project was obviously badly devised in many ways, but the chief cause of failure was that the wings were insufficiently run into the banks, and the water got round them.

No attempt was made after this to supply the city with water until the present project was undertaken, which has been successful, and forms the subject of this paper.

It was not an easy matter to decide what course to follow.

If it were possible to get a good large drainage area ensuring certainty of supply, and a good site for impounding the necessary amount of water at a moderate cost, there would be no question as to the advantages of such a project for supplying water; and if the city of Jeypore had been any where else in the State, some project of this sort might perhaps have been adopted, but the hills near Jeypore have no gathering ground, and there are no rivers near enough to the north of Jeypore, the only direction from which the levels would admit of water being brought by natural fall to the city.

The Bandi river was carefully examined.

The highest point that it begins to appear as a perennial stream is near Tantiawas; the supply is very scanty, and even here after making a weir 10 feet high which would be very expensive, the levels would only admit of a fall of 10 inches in the mile, the distance would be about 20 miles, the Amani Shah would have to be crossed by an expensive aqueduct, and the water even then would not be under pressure, and might in dry years fail altogether.

Any attempt to take water at a point higher up the river Bandi would necessitate the construction of a large reservoir, for which no good site exists, and which, even if there was a site, would be dependent upon the uncertain and scanty rain fall of these parts, and would require about 30 miles of duct to lead it off.

For these reasons the idea of using the Bandi as a means of supply was abandoned.

A suggestion was made to utilise the water in Bhao Sagar, alluded to above as a natural jhil, about 6 miles north of Jeypore, but the objections to this are that the water is very shallow and not good, the supply to it is not certain, and in two or three years the reservoir might fail, and there is no means of increasing the supply; also that the cost of taking a duct in contour through and round the hills and then filtering the water, would, considering the uncertainty, be a fatal objection to it.

Another suggestion was to sink a series of wells, connect them altogether by ducts below the water level, and then to lead the water to the city or pump it up. The former, I believe, is the system adopted in Afghanistan or other countries, and may answer where the levels admit, and where the supply is plentiful and certain and soil good, but here not one of these conditions are to be had, and as to pumping up, it is better to go to the Amani Shah nallah bed, where the supply is certain and water excellent, than to make any attempt at sinking wells elsewhere.

It seems to me, therefore, that the Amani Shah is really the only source on which we can depend, and it only remains to show how this has been taken advantage of.

The following is the report of the Government Analyst at Calcutta, upon this water:—

Total solid matter in solution, ...	24·00
Lime (CAO), ...	9·01
Magnesia (MGO), ...	1·66
Sulphuric Acid (SOZ), ...	0·41
Chlorine (equal to Sodium Chloride 2·3), ...	1·40
Hardness natural, ...	18·00
" after boiling 15 minutes, ...	9·60
Free and Albuminoid Ammonia, ...	0·0075
Nitrates, ...	None.

"This water is of excellent quality, sufficiently soft for all domestic purposes, and not containing more albuminoid ammonia than some of our best drinking water."

The Amani Shah rises in the hills immediately to the north of Jeypore. For the first 3 miles the bed is dry except in floods; after this it seems to tap the water-bearing strata around, and becomes a perennial stream. In the hot season its volume is only about two cubic feet per second.

At one time its bed was evidently much higher than it now is. This is shown by the plateaux here and there along the banks, which are now several feet above the present bed of the river, and also by the cuts showing where it was at one time possible to take off water.

The great slope in the bed of the river, 16 feet per mile, has caused a velocity in the flood which this friable soil cannot stand, and this lowering of the bed will no doubt go on until it gets to its normal slope, or finds a ledge of rock which will prevent it cutting back any more. I have in one day seen the bed of this stream lowered 12 feet by the breaking of a kutcha bund 2 or 3 miles up-stream. It has affected all the wells near; the level of the water in these has been reduced 10 or 15 feet in the last 10 years.

The problem was what to do with a nallah of this sort, to bund it up, or to tap it, or to raise water from it.

A kutcha bund, about 50 feet high, was made in the bed of the nallah at the foot of the hills as an experiment. It is there now, and fills up sometime 30 feet or so, but dries up in a few weeks. It was, therefore, not considered advisable to attempt anything of this sort for the supply of the city.

As regards tapping the stream, it was suggested that it might be possible to run a tunnel from the bed of the stream direct to the city, and take the water off in that way. The objections to this were—

(1). The expense and trouble of making a tunnel through the high ground between the nallah and the city. The height in many places being over 100 feet of loose sand, and the distance about $1\frac{1}{2}$ miles.

(2). The water could only be brought to the lowest parts of the city and would not be under pressure, and if the river dried at all, or the level of the springs in it altered, the duct would be left high and dry, and the expense and project would be useless.

Therefore the only scheme that seemed to promise success was to raise the water from the river, and it remained to decide where and how.

It might be interesting to mention that when the Rajputana State

Railway Engineers were preparing the plans for taking the line across this nallah, a suggestion was made to them to make a huge earthen bund across the nallah, and to take the railway and carriage road also over on the top of it. It might have been very easily done by taking soil in wagons from the up-stream side on each bank, and tilting them over at the site of the bund, and it could with energy have been done in one season.

There would have been a sort of reservoir formed on the up-stream side, which would have been useful in raising the level of the springs in the neighbourhood, and it might have saved us perhaps having to raise the water so high for the city as we now have to do. The cost would have been less than half what has been spent upon the expensive iron bridge which has been erected, and which is of no use except for the railway. The Railway Engineers, however, did not approve of this suggestion. I believe they feared the want of a proper waste-weir in such sandy soil, but I still maintain that these difficulties could have been provided for.

It was then decided to raise water from the river at the site of the old broken masonry dam, because there was certainty here of a perennial supply, it was the nearest point in a direct line to the city, and the materials and buildings which were at the site would be of use in any new works constructed here.

An anicut (*see Plate* I.) was thrown across the bed of the nallah from the broken dam to the opposite side. This was a masonry wall 6 feet high, 3 feet thick, founded on rectangular wells of masonry $9' \times 5'$ sunk 6 feet deep with intervals of 6 inches between them to prevent them jamming against each other while being sunk.

It is furnished with a sluice to admit of clearing out the bed when necessary, and it has been raised 2 feet to increase the supply of water.

On the down-stream side, broken material from the old dam and rubble were spread to form an apron of 1 in 12, reaching to within 2 feet of the top of the weir; where the water falls, it is further strengthened by a pavement of dry schistose slabs each about 12 feet long. These break the first fall of the water. They are all connected together by $\frac{3}{4}$-inch iron chain which passes through them all, and is secured to the wing-walls at each end.

The object of this weir is to prevent the bed of the river cutting any lower here, and to keep the pumps well supplied. It also serves to turn the water on to the filter beds until these are filled, when it acts as the escape for any surplus water which is not required for the filter. It serves also to give a 9 feet head to an hydraulic ram which is fitted here, and is used to supply the ice machines day and night.

The uncertainty of the working of wind-mills, as well as the size that would be necessary to produce the required power, made it advisable to arrange for steam power only.

The pumping house is 60′ × 38′, and is fitted with two pairs of 11 H.P. horizontal expansive steam engines, 12 inch cylinders, 24 inch stroke, of bright finished iron-work.

The pair first received were non-condensing, the other is condensing.

The effect of condensing is shown by the gauge as 13 lbs. per square inch, which represents on the piston an assisting force of 113 inches area × 13 = 1,469 lbs. Each pair is furnished with two sets of 9½ inch three throw plunge pumps, capable of throwing 36,000 gallons an hour, with gun-metal double beat valves, suction and delivery pipes, sluice valves, &c., connected to a wrought-iron air vessel 3 feet diameter 10 feet high; wrought-iron crank shafts 5¼ inches diameter, with plummer blocks and gun-metal bearings and coupling boxes for disconnecting either engine. There is a fly wheel 12 feet diameter, weighing 5 tons; this was in three pieces for conveniences of transit.

One pair only is usually worked, the other is always in reserve in case of any break down or extra supply being necessary. An air pump is fitted to the crank shaft, which can be used when necessary to keep the air vessel well supplied.

An indicator is also fitted to the crank shaft, which shows the number of revolutions made, and assists in checking the water pumped and fuel which ought to be consumed.

It would have been easy to have put up pumps capable of throwing a larger amount of water, but they would have increased the cost, and might have been unnecessary after all; the project is only intended to afford a supply of pure water for drinking or cooking purposes. There are plenty of wells in the city with water good enough to serve for other purposes, and by working all the pumps together or more often, the quantity now supplied, can still be increased.

The engines were supplied in the first instance with two egg-ended high pressure boilers 16 feet long 4½ feet diameter, but we have since adopted boilers of the Root's type.

These are considered more safe and economical. There is safety from any serious explosion, as the water and steam is subdivided in small wrought-iron tubes tested to 500 lbs. per square inch. Each tube is 5 inches diameter and $\frac{1}{8}$-inch thick (equivalent in strength to 24 inch tubes $\frac{3}{4}$-inch thick). They are lap-welded and not rivetted. Each tube is allowed to contract and expand freely, and is quite independent of the surrounding tubes, they are exposed to a more uniform heat throughout the entire length. Any part of the boiler can be lifted by three or four men, and this greatly facilitates carriage up country.

The tubes are inclined so that should water be mingled with the steam it is thrown downward to the back of the boiler, and by the connecting caps is conveyed to the lower tier of tubes. Should any tube give way it can be easily withdrawn, and a spare tube put in its place.

If the tubes get coated with soot they are easily cleaned by means of a steam brush; a rubber hose with iron nozzle is inserted and a jet of steam acts as a powerful scrubber.

In each flue there is a feed-water heater between the boiler and the chimney, which raises the temperature of the water considerably before it is admitted to the boiler.

The flue, sectional area 20 square feet, is taken up the bank, to the chimney which is erected at the top; total height about 72 feet.

The coals are stacked on the top of the old masonry dam, and are discharged through a shoot close to the boilers below.

Next to the boiler house is the ice factory 53′ × 30′, in which are two of Siebe and West's one-ton ether ice machines. We have made arrangements also which admit of these ice machines being worked by shafting from the water engines when these are at work; which saves fuel.

Steam can be supplied to work these, either from the Root's boilers in the boiler house, when these are under steam, or it can be supplied by a small independent boiler at one end of the ice house.

The slabs of ice are 5′ × 3′ in area and about 2 inches thick. They can be cut up to fit any size box by an ingenious contrivance made by Mr. John Baker, the Engineer in charge. Triangular shaped copper pipes are placed on a table with the apex uppermost at stated distances apart. The slab of ice is laid horizontally on these, and is pushed two or three times to and fro, while a jet of steam is sent through the copper tubes;

in about 10 seconds the slab is sufficiently cut at the required points to make division of it easy.

While the pumps are working it is easy to keep a current of water playing over the refrigerator of the ice machine, but at times in the middle of the day in the hot weather, the temperature of the water pumped up from the river bed is 94°, and as ether boils at about this temperature, it becomes necessary to draw water by a small donkey pump from the bottom of a covered-in well sunk in the bed of the river about 20 feet.

When the temperature admits, water is pumped up by a small hydraulic ram placed just below the anicut at the foot of the apron.

The inlet pipe is at the top of the anicut 7 inches in diameter.

The outlet from the ram is 2 inches, and it forces a jet of about 26 gallons per minute into the ice house, a height of about 22 feet, day and night of its own accord, after being once set going.

The filter is situated in the bed of the river south of the old masonry broken dam, which protects it from floods. It is fed by an open masonry duct from the anicut, and as soon as 1 foot 9 inches in depth of water has passed into it, the level of the water is then flush with the top of the anicut, which serves as a waste-weir, and prevents the filter overflowing.

The area (*see Plate* II.) is 160′ × 80′, depth 5 feet 3 inches, is made up as follows :—

	ft.	in.
Water, ...	1	9
Fine sand, ...	2	0
Coarse sand, bajri, ...	0	6
Broken stone ¾ to 1½ gauge, ...	0	6
Covering slabs to drain, ...	0	2
Height of drain, ...	0	4
Total, ..	5	3

There is a slight slope towards the centre from both ends, so that the water after passing through the filtering strata runs to the centre, and from there passes into a small covered tank, from which it is drawn by the pumps in the engine house.

When the filter has been emptied, air will accumulate in the 4 inch hollow spaces on the floor, and to give this air means of escaping, small tubes are inserted at the higher ends, and rise above the high water mark.

The area of the filter is made large enough to allow of sufficient water passing through at the rate of 6 inches in an hour to keep the pumps well supplied.

The supply can be shut off at any time, and a valve communicating with the bed of the river allows all the water from the filtered water tank to escape when it is desired to empty the filter completely.

The drains or hollow spaces on the floor in our case have been covered with slabs, so as to make a sort of false floor, upon which the broken stones are placed. Experience has proved that these slabs should fit as close together as dry bricks, and should be let into the wall all round, or sand may find its way in through the openings or down the faces of the side walls.

Whenever it is required to clean the filter, all that is necessary is to allow it to stand quite empty for a day, and then remove the upper inch or so of mud from the surface. The sand can be renewed whenever it is necessary.

At first it was intended to make covered tanks in the bed of the river, leaving a thick bank between them and the river, and to make this serve as a filter, but the plan which has been adopted was found to be the best and least expensive, and has the great advantage that the filter can at any time be cleaned.

By a simple arrangement of valves below the pumps, it is possible to draw the supply all from the filter, or all direct from the river as may be desired.

If the filter could have been put immediately below the service reservoirs, the filtered water could have been passed at once into the service mains, but this would have reduced the head more than was desirable.

The service reservoirs (*Plate* No. II., or Index Map *Plate* No. I.), two in number, are placed on the highest ground in the neighbourhood, distant from the pumps about 2,000 feet.

The bottom is 103 feet above the pumps, and 36 feet above the pavement in the city squares. They are each (*see* Sheet II.) 150 × 100 at the bottom, 15 feet deep, containing each 236,385 cubic feet = 147,740,625 gallons, and can be filled in 48 hours by one pair of pumps.

The water is brought by a 9 inch main from the pumps to the top and is admitted by a 3-way valve to either reservoir, and falling through the air into the tank has no doubt a beneficial effect upon the water breaking and aerating it to some extent.

The outlet to the city is by a 12 inch screw valve fitted with gauze wire strainers.

When it is required to clean out these reservoirs, the main to the city is closed, and a small branch is opened through which the waste water and dirt is passed off.

An upright tube, 1 inch diameter, is inserted at the highest point near the head of the main to allow the escape, when the pipes are being filled, of any air which may have accumulated in the main when it was empty.

It is intended eventually to roof in these service reservoirs, as water should not be allowed to see the light after it has been filtered until it is drawn for use. A water level indicator with a double dial with floats (*Plate* No. II.) has been placed on the division wall between the two reservoirs, which enables the Engineer from his quarters to see the depth of water in each reservoir; one reservoir is always in use while the other is being filled.

A 12 inch main takes the water to the city, where it is distributed by pipes of smaller dimensions to the palace, several streets and the public gardens and hospital. A pipe of smaller diameter would have been sufficient for ordinary requirements, but there are bathing tanks in the palace which have sometimes to be filled, and if a smaller main had been adopted, it might have interfered with the supply elsewhere when those tanks were being filled.

To enable the mains in the city to be scoured out, scouring valves are fixed at the lowest points on the line of pipe, or where there are means of passing off the discharge, and these are opened about once a week, and are allowed to run for a few minutes. All pipes from 3 inches and upwards are of cast-iron dipped in Dr. Angus Smith's solution, and all below 3 inches of wrought-iron galvanised.

For distribution the following arrangements have been made. There is a stop valve for each street, so that at any time it can be shut off. Stand posts have been erected at the corners of all the streets which intersect the main line of pipes, these are placed at such a distance apart from the main (generally about 20 feet) as to allow of a stop valve being placed on the branch, so that the water may be shut off at any time from the stand post.

Self-closing ball stand posts were first tried, and for filling *ghurrahs* answer well, but are not suitable for drinking purposes, too much water comes out, and it splashes the drinker. The same objection applies to the Kennedy Pillar, also self-closing.

Another sort was also tried, the water from which issues when the brass stud is pressed down, and this answers for drinking as well as for filling vessels, but the objection is that the spring below the stud often requires repair.

The stand post which appears to answer best is shown in *Fig* 1., *Plate* III. It is a 4-way post, two taps ¾-inch are for filling vessels, and two small ⅜-inch are for drinking purposes. The latter is furnished with a diaphragm with a small hole in the centre, which allows just enough water to escape for a man to drink. The cost of this at Jeypore is Rs. 85-0-0. The stone step at the base is convenient, it allows one foot to be raised so that the water vessel while being filled can be rested on the knee.

As natives generally drink with the right hand to the mouth, and the left to keep their clothes clear from the waste or any splashing from the water even, about which they are very particular, it is advisable to have some plan which, after the water has been turned on, leaves the hands free for these purposes, and *Fig.* 2 shows a simple arrangement which meets all requirements.

The tap is a simple ¼-inch screw, down bib cock, and the basin below catches all the waste.

In England these bib cocks, from carelessness or mischief, would no doubt be continually allowed to flow and waste water, but I have never seen an instance of this sort in Jeypore yet.

For bhistees a 1 inch or 1¼ inch bib cock with screwed end enables a piece of leather or rubber hose, about 10 feet long, to be attached, this enables camel or bullock *packals* to be easily filled, and bhistees also to fill their *mussacks* without trouble.

A cut stone pavement is placed round each stand post, and the waste water runs off into small drinking troughs for cattle.

Where especial arrangements are desired, as for stables or cattle sheds, a trough is made, and is supplied with an ordinary copper ball valve. As cattle drink it allows just that amount to be replenished, and when the trough is full is self-acting and shuts off the supply; all wastage is thus prevented.

The tanks in the city squares which were alluded to on page 216 as having been made in connection with the masonry dam project, after the failure of the dam, became simple receptacles of rubbish; these have been cleaned out, and the depth lessened to 3½ feet.

In the centres ornamental fountains have been erected which play daily from 4 p.m. till dusk, and at one side *Gao Mukkhi*, or cow heads, in marble, have been erected for bathing purposes. The cow head is fixed high enough to allow the water to fall over a man's body, and on turning the tap, issues from the mouth of the cow head, which natives consider a great advantage. In white marble these only cost Rs. 7 each.

About 35 private houses have had water laid on. All these pipes and connections are of wrought-iron with brass valves.

The Mayo hospital is provided with taps for tatties, shower baths and other purposes; and the operating room has a special arrangement of about 20 feet of india rubber hose, and a copper nozzle to regulate the discharge, and is found very convenient, as it enables a jet of water to be used during operations at any moment, and at any point in the room; this is a step in advance of the bhistee and *mussack* supply, so often seen in Indian hospitals, and which every Surgeon must have found so inconvenient.

In the Ram Newas Garden (*see* Index Map) a 6-inch main is taken throughout the length on the north side, and completes the circuit of that portion, which is an advantage, as in case it is necessary to shut off one inlet, water can be supplied from the other.

This main is furnished with hydrants and copper stand pipes, to which leather hoses can be attached with copper nozzles for distribution. The main is also connected to three or four of the most important wells, so that when more water is required than the wells can yield, which occurs in the hot season now and then, it is possible to take water from the main. The water is discharged into the well trough, and follows the usual course of the well water, so that the existing channels can be utilized.

In the plant house, where a jet of water is sometimes required, flexible hoses and spreaders are provided, also an overhead perforated pipe, which allows a spray to descend like rain, and a hidden pipe through a rockery allows a continual dripping over the ferns and plants in the caves below it.

A circular fountain jet also throws a horizontal spray as it revolves of itself, all round over those plants which require a larger supply of moisture.

No water rate is levied on the city, the water is the gift of the Maharajah to his people, but the dyers and confectioners who use this water largely in their trades, and will not provide themselves with taps, are charged a water rate of 8 annas each per month, or are prohibited from using the stand posts in the streets.

For private houses the following arrangement is made—all connections outside (including a stop cock) are placed at the cost of the water works, all pipes and connections and fittings inside private limits are at the cost of the applicant.

In case of any application for water an estimate is prepared, and when it has received the approval of the applicant for his share, and then of the Durbar, the work is carried out.

The water rate is collected at the beginning of each month in advance, and if it is not paid the stop cock outside is closed and the water shut off.

The following rates are charged :—

	Rs. A. P.	
For the first tap (of any size)	1 0 0	per month.
Second and every other tap, ...	0 8 0	,, ,,
For a drinking tap *pro bono publico* or for cattle, ...	5 0 0	,, ,,

This is the highest charge made, Rs. 5, and the payer can have as much water as he wants ; excepting for garden purposes, for which it is not allowed.

It is not used in watering the streets, as these can be watered cheaper by bhistees from the existing brackish wells at the road side.

The average cost of the water supplied, is about 4 annas per 1000 gallons, this does not allow of any reserve fund for interest or renewals, which in this case is not necessary. I believe at Calcutta the rate for 1000 gallons is Rs. 0–10–8; at Bombay Rs. 0–12–0.

What adds so much to the cost is the heavy item of fuel. Wood is not to be had in any quantity, and coal which at Raneegunj costs Rs. 4 per ton, costs nearly Rs. 40 per ton by the time it is delivered at the water works.

Some natives had scruples at first against taking the water, and others said that giving them water from a dog's mouth (it really is intended for a lions's head stand-post) was an attempt to make Christians of them, but as no compulsion was used, and every one was left to do as he liked, common sense prevailed, and these objections are gradually giving way.

The average daily consumption for the past year has been about 253,000 gallons. This however includes 365,667 cubic feet which were supplied to the Ram Newas during the year, and the water used in filling the bathing tanks in the city.

That natives appreciate good water is evident from the prices they will pay for it: in Agra water drawn from the river and sold by hand in the city fetches as much as I believe Rs. 3-7-0 per 1,000 gallons. While in Jeypore the water which is drawn from wells and taken by some persons, in preference to water from the stand-posts in the streets, costs about Rs. 2 per 1,000 gallons.

In order to remove any scruples which might exist, the Maharajah invited a Committee of Pundits to inspect the machinery and satisfy themselves that there was nothing contrary to their ideas of purity.

They examined everything, and as the leading member of the committee had water laid on the next day to his temple, it is evident there could be no valid objection.

The actual work in connection with distribution only, which has been executed up to date, is shown on Table A, and the expenditure incurred on the whole scheme can be seen from the Abstract Estimate herewith attached, Rs. 4,75,113.

The cost of maintenance for the past year is Rs. 26,253, and is made up as follows:—

	RS.
Establishment, ...	6,908
Fuel, ...	18,929
Sundries, ...	416
Total Rs., ..	26,253

The Establishment consists of—

1 European Engineer.

1 „ Assistant Engineer.

2 Native Drivers.

30 Firemen, Cleaners, Oil-men, &c.; this is sufficient for three relays working 8 hours each.

The European Engineer has also to look after the ice factory during the hot season.

During the past year the engines worked on an average 9 hours and 12 minutes daily, raising 310,512 gallons daily.

All the machinery, pipes, &c., connected with this project have been got direct from Messrs. J. C. and W. Lord, 142, Great Charles Street, Birmingham, who have given us entire satisfaction.

TABLE A.

Detail of works performed in connection with City Water Supply, Jeypore, Rajputana, shewing distribution of pipes, &c.

53	Drinking Posts.
10	Hydrants.
9	Bhistees drawing taps with leather hoses.
31	Fountains with jets of sorts.
90	Bib cocks.
24	Stop valves from 12" to 3".
118	" " of sizes.
2	Shower baths, Mayo Hospital and the Palace.
12,541	R. ft. 12" Pipes.
6,837	" 9" "
15,724	" 6" "
7,035	" 3" "
1,902	" 2½" "
2,133	" 1½" "
322	" 1¼" "
2,829	" 1" "
4,074	" ¾" "
4,495	" ½" "
400	" ¼" "
137	" 1" India rubber hose.
638	" ¾" " " "
305	" ¾" Pipes drilled with holes for supply to khus tatties.

Rate of Pipes received from Messrs. J. C. and W. Lord of Birmingham, including all charges, delivered at Jeypore.

Description of pipe.	Rate per running foot.		
	RS.	A.	P.
12" Cast-iron pipe, ...	7	12	10
9" ,, ,, ,, ...	5	8	7
6" ,, ,, ,, ...	2	5	10
3" ,, ,, ,, ...	0	13	8
$2\frac{1}{2}$" ,, ,, ,, ...	0	12	6
2" Wrought-iron,, ...	0	10	11
$1\frac{3}{4}$" ,, ,, ,, ...	..	..	..
$1\frac{1}{2}$" ,, ,, ,, ...	0	8	9
$1\frac{1}{4}$" ,, ,, ,, ...	0	6	1
1" ,, ,, ,, ...	0	4	6
$\frac{3}{4}$" ,, ,, ,, ...	0	3	1
$\frac{1}{2}$" ,, ,, ,, ...	0	2	5
$\frac{3}{8}$" ,, ,, ,, ...	0	1	6
$\frac{1}{4}$" ,, ,, ,, ...	0	1	2

ABSTRACT OF EXPENDITURE.

Detail of Expenditure.

No.	Particulars.	Amount.
		RS.
A	Weir in river, ...	8,578
B	Pumps, ...	73,575
C	Engine house, &c., ...	16,557
D	Boilers, ...	34,138
E	Boiler house, ...	5,775
F	Service reservoirs, ...	43,295
G	Pipes, ...	2,64,547
H	Miscellaneous, ...	14,413
J	Gas works, ...	602
K	Workshop and godown, ...	5,259
L	Establishment, ...	8,374
	Total Rupees, ..	4,75,113

S. S. J.

ANI SHAH AT THE SITE OF PUMPING ENGINE.

nch.

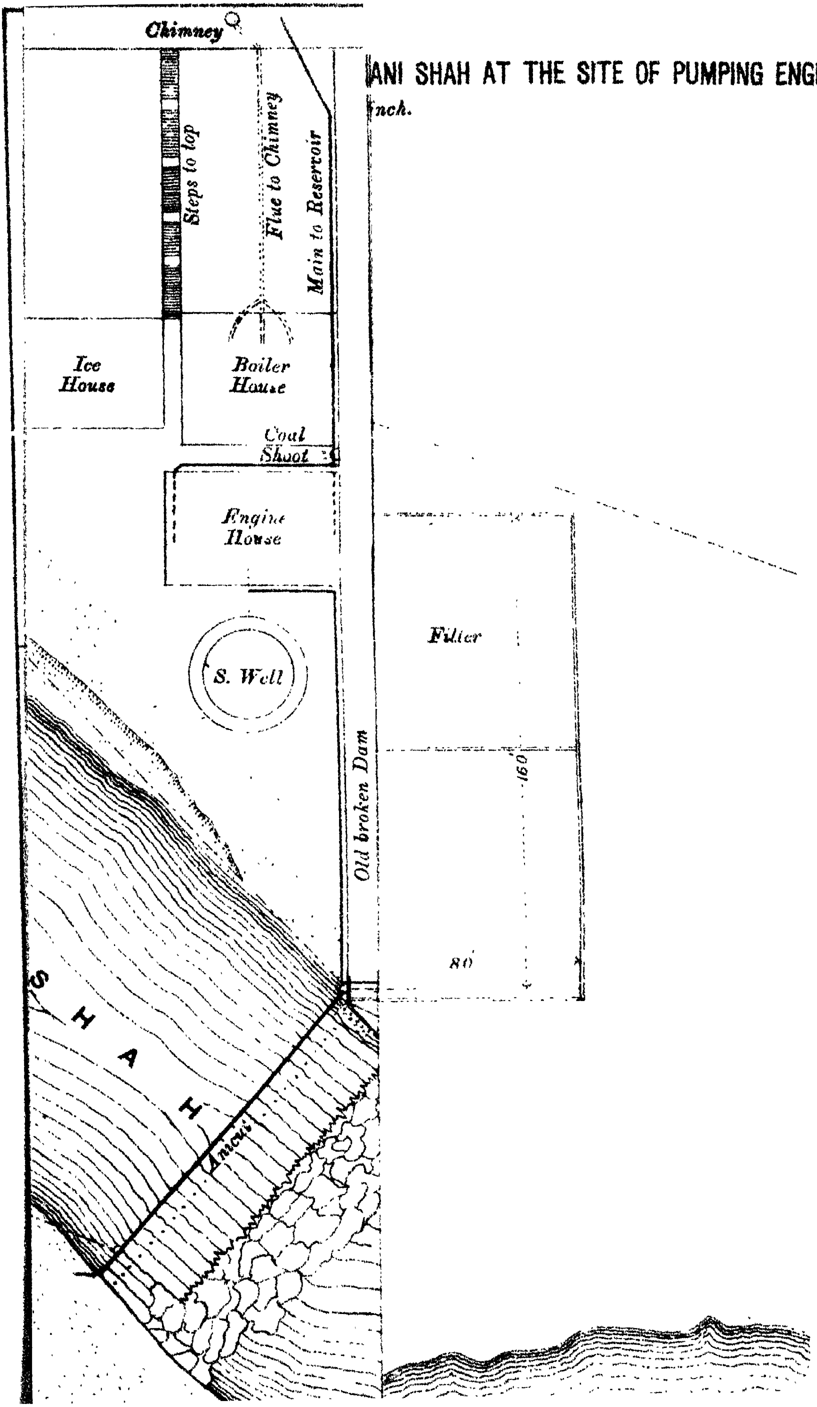
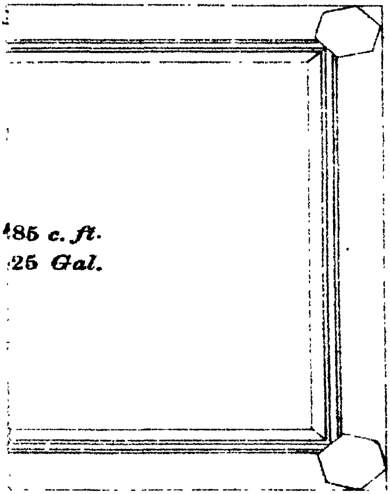


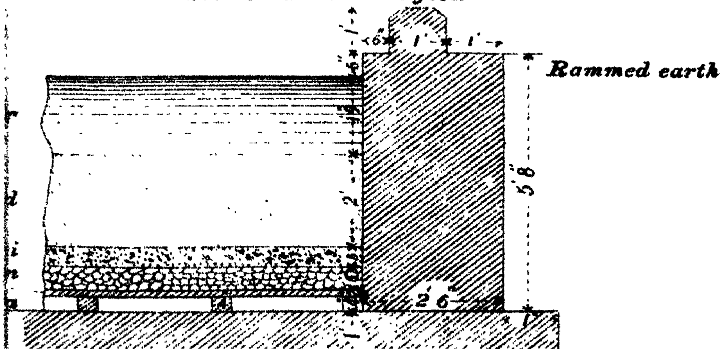
PLATE II.



SECTION OF FILTER. SEE PLATE I.

Shape Rectangular—160′ × 80

Scale. 1 *inch* = 4 *feet.*

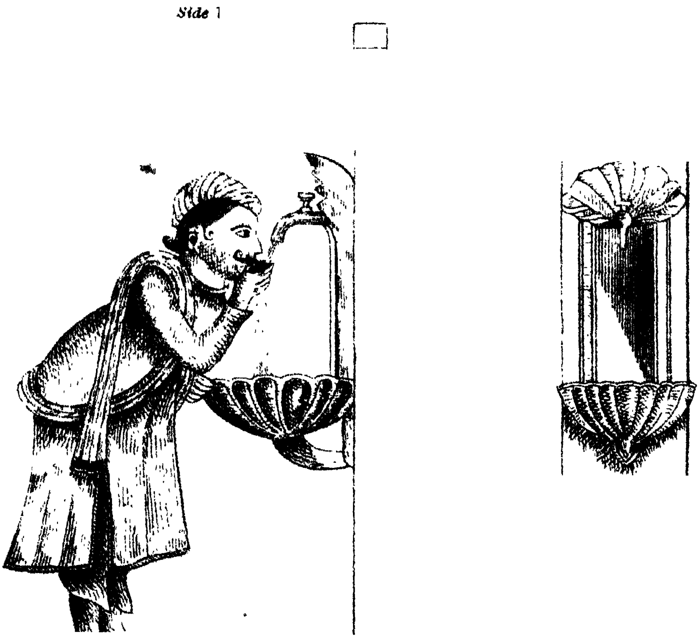


JEYPORE CITY WATER SUPPLY.

Scale. 1 *inch* = 2 *feet.*

FIG. 1. 4-WAY STAND POST.

FIG. 2. DRINKING TAP.



No. CCCVIII.

CHEAP WELL FOUNDATIONS.

By B. W. Blood, Esq., *M. Inst. C.E., Exec. Engineer, Rajputana State Railway.*

The experience described below is believed to be a novel mode of getting down moderately deep foundations when the soil is not too wet to allow a well to be kept dry.

On the Sambur Nawah Extension of the Rajputana State Railway, the line near Nawah is carried across a bay of the Salt Lake, into which runs, during the rains, a river which drains about 100 square miles of country. The river is one of the largest feeders of the Sambur Lake, and, as may be supposed, at times discharges a very considerable volume of water, which will be passed by a bridge, 40 spans of 20 feet.

The bed of the lake at the site of the bridge is composed of about three feet of a stiff mixture of clay and sand, below which, for about 13 feet, is a kind of quicksand with thin beds of kankar at intervals, till at about 15 to 17 feet a thick band of soft scaly half formed sandstone is reached. The foundations were to be oval cylinders, 13 and 11 feet major and minor diameters, splayed out at the bottom, and in order to found them upon this hard bed, well steining or tubeing of some kind would be required for the excavated wells to keep out the water and slush. On account of the expense of a regular well steining and curbs, and the delay they would cause, it was decided to adopt a steining of sirpat grass sunk as is done, in their kutcha wells, by the natives of the North-Western Provinces. This steining was made of the long jungle grass, which grows plentifully in that part of the country, formed into a hard roll 8 to 9 inches in thickness, which was led into the wells, and packed coil under coil as the work went down. The internal form of the wells was maintained with great care, and the diameter was increased by splaying out the last few feet to give a larger base. In this manner the wells were carried down to the required depth, one foot into the hard material, when they were filled in with 12 feet of a concrete, composed of an eminently hydraulic kankar lime, kankar, bajri and sharp broken stone. This concrete sets into a mass of rock, and gives in every way as good a foundation as if a masonry or brick well had been sunk to the same depth.

The masonry of the piers begins on this concrete, *i.e.*, at about five feet below the present lake bed, and it is expected that the concrete will not be exposed by any scour which may occur.

B. W. B.

Jeypore, 7th May, 1879.

No. CCCIX.

ALLUVION AND DILUVION ON THE PANJAB RIVERS.

[*Vide* Plates I. and II.]

By E. A. Sibold, Esq., *Executive Engineer.*

In this paper it is proposed to deduce from a few observations the law or laws on which diluvion and alluvion take place in a river flowing through a sandy plain unhindered by rock or any other foreign obstacle. The observations chiefly apply to the Panjab rivers, and more particularly to a ten mile reach of the Chenab in the neighbourhood of Multan. An attempt will be made to show how the movements and changes in the spirals represented by the deep stream ACB, (*Fig.* 1,) can be made susceptible of investigation. The theory is that such spirals progress down-stream, and that their action or progression is the sole index of all river changes. It is alleged that in the course of time the diluvion of *b*, (*Fig.* 2,) becomes the alluvion of B; diluvion of *c* the alluvion of C; and so on. The spiral is, however, only the local sign or effect of an oscillation or disturbance extending from the mountains to the sea. This oscillation or work of re-adjustment of declivities in a stream is unceasing. The progression of a particular spiral is only a particular effect of this unceasing action, and it has a varying course from initiation to exhaustion. The important point is the local action on local works, *i.e.*, the progression of this spiral, and the results when it is meddled with.

To avoid obscurity in the illustration, the deep stream has purposely been made very prominent in *Fig.* 1. A few of the minor and spill channels are shown in dotted lines. Facts will be given further on to show that it is reasonable to suppose that the minor channels simply perfect the work of building up the alluvion. The two deep streams shown as existing opposite Faridabad in 1855-56, would not give a case of altered conditions; they would simply make it more difficult to follow the working of the spirals.

Before going into details, it is necessary to define some of the terms used.

Cutting edge, or the line on which diluvion or erosion is taking place. This is the length of bank on concave side of deep stream which is being eaten away. The term does not refer to accidental scour from a local obstruction such as a snag.

Bank.—This is the bank bounding the deep stream, whether recently thrown up or permanent.

The Spiral.—If ACB (*Fig.* 1) is the spiral whose action is to be investigated, the first cutting edge is at A on right bank; the next at C on left bank; the third at B on right bank again. None of these cutting edges will have the same energy. It is necessary to ascertain whether energy of cutting edge C is due to impulse from A; that of B to that of C. If B show signs of exhaustion, and C of greater energy, then cutting edge at B was due to a previous impulse, and a new cutting edge, more or less developed, will be found on reach BC dependant on C. The energies of the cutting edges are interdependant, but great care is required to detect the marshalling of the series where old spirals are disappearing and new ones appearing.

Point or Line of Quiescence.—This is the point of contrary flexure on the spiral. The cross-section of the stream should here approximate to the regular trapezoidal section of a canal. It marks the up-stream limit of safety when selecting the site for the head of an inundation canal. It is the point or reach of river where the regimen of the stream is established for the time being.

The next point is to describe the cause of the progression of the spiral. Diluvion only takes place in an elbow or concave bank of the stream, (see cutting edges in *Fig.* 3,) and this elbow is really a barrier or spur in the river. Now this barrier causes the water to rise above its normal level, and a rapid or cataract (perceptible on levelling) is required immediately below to connect the two water levels. The draw thus obtained should make the diluvion or erosion most severe in the immediate vicinity just above, and the cutting edge therefore progresses down-stream.

To connect the theory with the observations in detail, it will be necessary to consider the following.

The transfer of the sand banks from side to side is the immediate cause of the evolution of the spirals. According to *Fig.* 2 whatever is cut away at *b* proceeds to B; from *c* to C, &c. A complete act of diluvion at *b* results in a complete act of alluvion at B, and in a complete reversal of the spiral the sand banks on one side are transported to the opposite side. In other words, the atoms of sand swept off the cutting edge must follow the tangent to the curve of this cutting edge, and proceed to the nearest alluvion down-stream on the other side.* The layers of silt or clay of varying thicknesses usually found in deposits may be derived from a thousand sources, but the sand, the bulk of the deposit, describes a spiral path, and then has a period of rest. If the bulk of the deposit was derived from a thousand sources, unceasing change would not be the marked feature of these rivers; the tortuous course would be induced once for all, and changes would be perceptible in ages only: not in years. This distinction between deposits merely pushed onwards and sediment held in suspension, is probably the most important fact in river hydraulics. Deposits of sediment tend to raise the general level of a channel, for instance the river Po; the spiral action tends to lower the level. The former action applies to all rivers, the latter only applies to those whose regimen is not established.

The writer has observed a shoal treading on the heels as it were of a cutting edge, at the three following places:—

1. Langar Serai, (*Fig.* 2, C and *f*, and *Fig.* 3.)
2. Faridabad, (*Fig.* 2, A and *d*,) the consecutive cutting edge on right bank up-stream of No. 1.
3. Kharakwala on the Indus, (*Fig.* 4.)

The changes in position of cutting edge and shoal at Langar Serai between February 1878 and March 1879 are given in *Fig.* 3. In that interval the cutting edge advanced about three miles; the shoal advanced

* The progression of the shoal in rear of the cutting edge can only be accounted for in this manner.

somewhat, but not to the same extent. The shoal now shows signs of tapering off, and the kink in the elbow or cutting edge is flatter. In the absence of actual measurements of AB, BC, and CD, (*Fig.* 5,) all that can be said is that the state of matters at Langar Serai in March 1879 was approximately the state of matters at Faridabad in February 1878. In March 1879 the work of diluvion and alluvion at Faridabad appeared almost perfected, *i.e.*, the energy of this particular spiral action was nearly exhausted. It is assumed that the energy at B and *e* is an intermediate between the energy of the spiral action as shown at Langar Serai and Faridabad, because the evident interdependance of the diluvion and alluvion at Faridabad and Langar Serai requires a corresponding condition of things at B and *e*, and so on through the whole series. This single partial serial observation is only presumptive proof, and each man will have his own idea of its conclusiveness. Again at Kharakwala on the Indus, the shoal and cutting edge present the same characteristics as at Langar Serai, and here too the shoaling of the up-stream spurs and the necessity of adding on new spurs below prove the simultaneous progression of shoal and cutting edge down-stream. This case also fulfils some of the most important conditions required by the theory. The exigencies of work only incidentally led to a fuller knowledge of the working of the rivers at these points, and then to the belief that the best way to understand a river was simply to observe the progression of a consecutive series of cutting edges. This will account for the gaps in the above illustrations.

The next noteworthy point is that the flattening of the elbow and the tapering of the shoal tend to give a straight reach to the river in its quiescent stage, *i.e.*, when the velocity (the dependant variable of the fall or slope) is proportioned to the regimen. In the case of the Sidnai reach of the Ravi river, the usual stability of a few years only has become the stability of centuries. The Sidnai is a straight reach of the Ravi, 9 miles long, and it has not altered its present channel for at least three centuries, judging from the banyan trees *overhanging the channel.* The Sidnai must like river channels, on which the spiral action is absent, be gradually rising from deposit of sediment, but the conditions for spiral action, or the *pushing forward* of *sandy barriers* are wanting. The advance of the spiral is the same thing as retrogression of level in a canal, and the effect of *sedimentary* deposit is the same thing as deposits of silt at the heads of most rajbahas (at least on the Bari Doab Canal), or the gradual rise of the bed of a river like the Po.

It is said that cases can be quoted of the cutting edge or diluvion proceeding up as well as down-stream. It has been stated that the diluvion is the result of the draw below the elbow or concavity of the spiral. If the discharge is increased, the influence of the draw will extend further up-stream, and an apparent retrogression of the diluvion will take place. If a really new diluvion is developed up-stream, it is simply a case of one oscillation overtaking another.

Mr. Garbett, Superintending Engineer, Derajat Circle, drew attention to the following apparent paradox some years ago.

The discharge of the Indus river in December 1874 was found to be 26,000 cubic feet per second, and in December 1875 only 23,000 cubic feet, though the gauge gave a 1·8 foot higher reading. In January 1875 it was 28,000 cubic feet, and only 21,000 in January 1876, with the gauge reading 2·35 feet higher. The ponding up caused by the developement of a cutting edge below gauge after December 1874, would explain satisfactorily the reason of a gauge reading being no criterion of discharge on the Indus.

In *Fig.* 1 the minor channels are shown in dotted lines. In *Fig.* 3 a network of them are shown at right angles to the cutting edge. In the case of this particular network of channels, some were perennial in February 1878, but all were mere spill channels in February 1879. The alluvion flush with flood level had also increased considerably; in the depression this network of channels meanders through. This is what is meant by the statement in the first paragraph,—these minor channels perfect the work of building up the alluvion. It was expected (owing to imperfect knowledge at the time) that the great floods of 1878, the greatest for at least 20 years, would have been swept down the direct line presented by these channels, and so have altered the whole course of the river for 10 or 12 miles. These floods did *not alter* the action of the spiral. At Kharakwala also there was no alteration in direction.

To prevent misunderstanding, it is as well for the writer to state something about his ideas of protective works. The spiral action is not irresistible, and if a more powerful barrier bars its progress, the spiral action simply exhausts itself against this barrier, and an imperfect oscillation is the result. The well secured abutments of any of the State Railway Bridges in the Panjab are instances of immoveable barriers. A most misleading experience is often gained in the case of the so-called training river works. The "Brownlow" weed spurs which answer on minor channels, would be useless on or near a cutting edge. One man has the good fortune to put in his training works when a spiral action is on the wane; another the misfortune to start his works when it is in embryo. The works of the former probably stand; the works of the latter probably fail, the result being that the two men will have exactly opposite opinions of the efficacy of spurs, &c.

The progression of the spiral is not a necessary condition on all rivers, because this progression requires a sandy bed and steep declivities. The specific gravity of the sand must be so great that it cannot be held in suspension like fine clay, but must be pushed onwards. The two extremes are mountain streams, where the continuity of the deep stream action is broken by rapids and cascades, and rivers with small slopes like the Amazon. The following few notes on the Panjab rivers indicate circumstances under which spiral action may be expected.

It is a very old axiom that tortuosity is due to excess of slope. The three important factors in river hydraulics are, hydraulic mean depth, volume of discharge, and slope. The question of choice of formulæ and coefficients is a very important detail, but has nothing to do with principles. Exact figures of the hydraulic mean depths of these rivers might be obtained from the Department Public Works records. It is sufficient for the purpose of this Paper to say that the differences between the maximum and minimum levels of the water surface are much the same in all the rivers. It varies in different years from 10 to 13 feet. The depths when the rivers are at their lowest are also insignificant. Where no violent diluvion was taking place, it would be difficult to obtain a greater sounding than 6 or 7 feet on the Sutlej; of 8 or 9 feet on the Chenab; and of 15 feet on the Indus. The cold weather discharge of the Indus varies from 20,000 to 36,000 cubic feet per second; its ordinary flood discharge is 580,000 cubic feet. The discharge of the great flood of 1858 was 1,514,500 cubic feet per second, approximately. The cold weather discharge of the Sutlej varies from 6,000 to 10,000 feet, and its flood discharge is about 200,000. The Chenab and Jhelum are about the same size as the Sutlej, and the Ravi is much smaller.

The following are the declivities, the rivers being placed according to size:—

Indus,	..	..	..	..	1·33 feet per mile.
Chenab,	..	..	..	..	0·97 ditto.
Sutlej,	..	..	..	..	2·00 (approximately).
Jhelum,	..	..	..	..	1·51 (ditto.)
Ravi,	..	..	..	..	2·00 (ditto.)

If the District maps (2 miles = 1 inch) are examined, and 50 mile reaches of these rivers are compared, it will be found that degree of tortuosity bears a relation to the above noted declivities.

The spirals of the Sutlej and Ravi will be found very similar, and their courses most tortuous. The Chenab will be found to have the flattest spiral. On account of its much larger volume, the Indus should be at least as tortuous as the Sutlej or Ravi. That this is not the case, and that like on other rivers the comparison of tortuosity to declivity holds good, is due to its shallowness and the division of its volume among two or more cold weather channels. In December and January last the gauge at Dera Ghazi Khan did not vary a tenth of a foot, and for about 15 miles above and 5 miles below, or on a reach 20 miles long, the river was, if any thing, shallower than at the point of observation, and here the hydraulic mean depth was 4·33 feet, with a discharge of 34,181 cubic feet in two channels. The Indus always flows more or less in two or more channels. It is deduced from this that its insignificant hydraulic mean depth and the loss of energy resulting from splitting up into several channels puts the Indus on a par with the Chenab, Sutlej, &c. There are of course local cases of a great hydraulic mean depth. At Kharakwala (*Fig.* 4) nearly the whole of the Indus (at least 32,000 cubic feet per second) was contained opposite spur No. 7, in a channel 375 feet wide with soundings up to 50 feet. This great contraction extended, however, scarcely 1,000 feet, and the stream broadened out rapidly above and below. Compared with the discharges the hydraulic mean depths of these rivers are remarkably insignificant. In all rivers where such is the case, it will be found that coarse sand predominates, and the declivities are great, and spiral action is the most prominent feature. The particles of fine clay that require absolutely stagnant water for deposition, and the variations of discharge modify the clock work regularity of the spiral action. The Hydraulic Engineer Surveyor should, however, seek to fix on his map the position of the cutting edges, the lines of quiescence, and the curves of the deep stream.

The practical application of the theory to inundation canals, bridge and other river works, must be reserved for another paper.

In conclusion it may be noted that this Paper has been re-written at the request of the Editor. His criticisms,* as also those of Mr. S. Hanna, Executive Engineer, are now incorporated in this exposition of the theory.

MULTAN: } E. A. S.
17*th June*, 1879. }

* NOTE.—Editor is in no way answerable for views of any contributor, but welcomes this endeavour to find a rule on which river training works may be based, as he believes much money may be wasted in spasmodic efforts to influence a large river at a particular locality unless the general and almost irresistible action of the river is taken into account.—[ED.]

ALLUVION AND DILUVION ON THE PANJAB RIVERS.

Scale. 2 inch = 1½ mile.

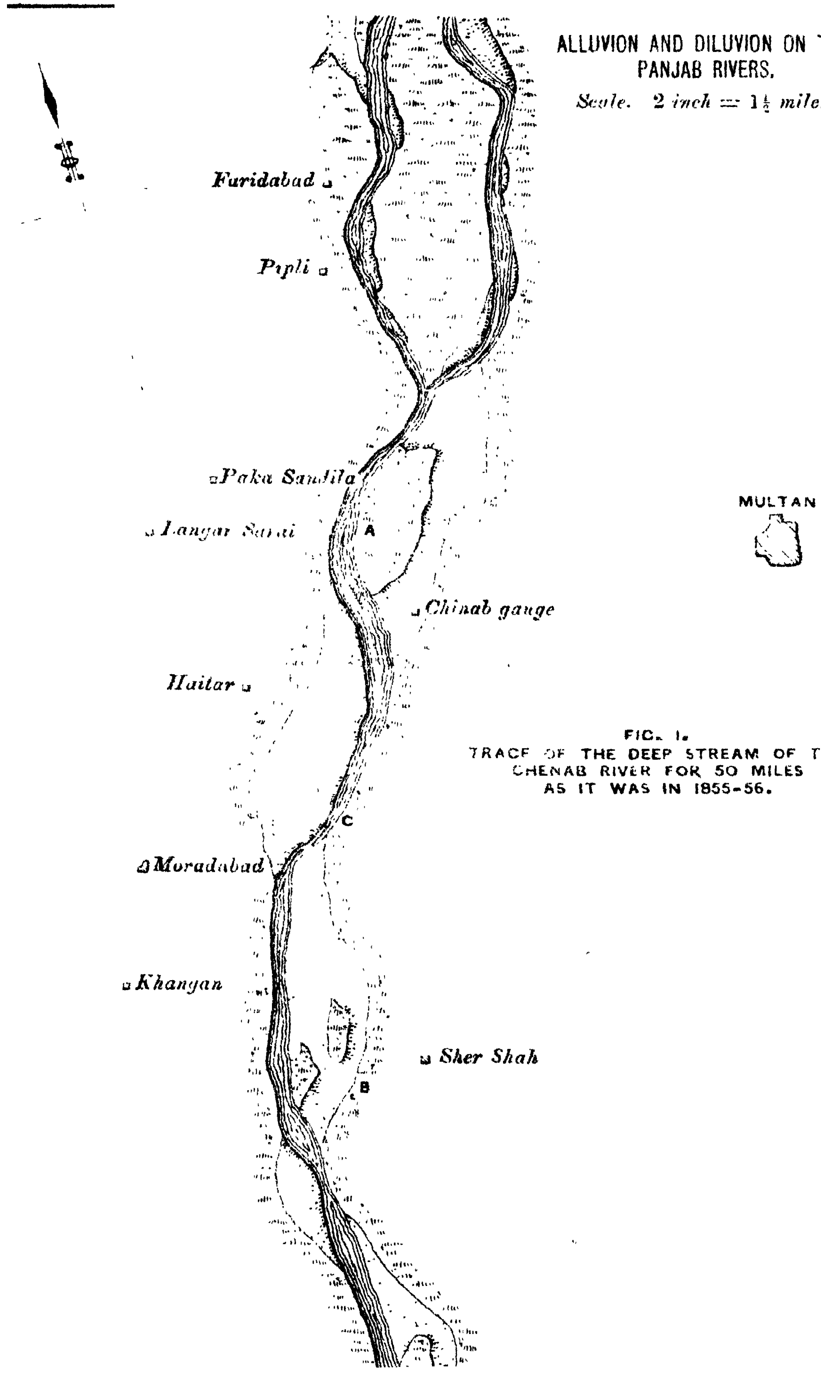


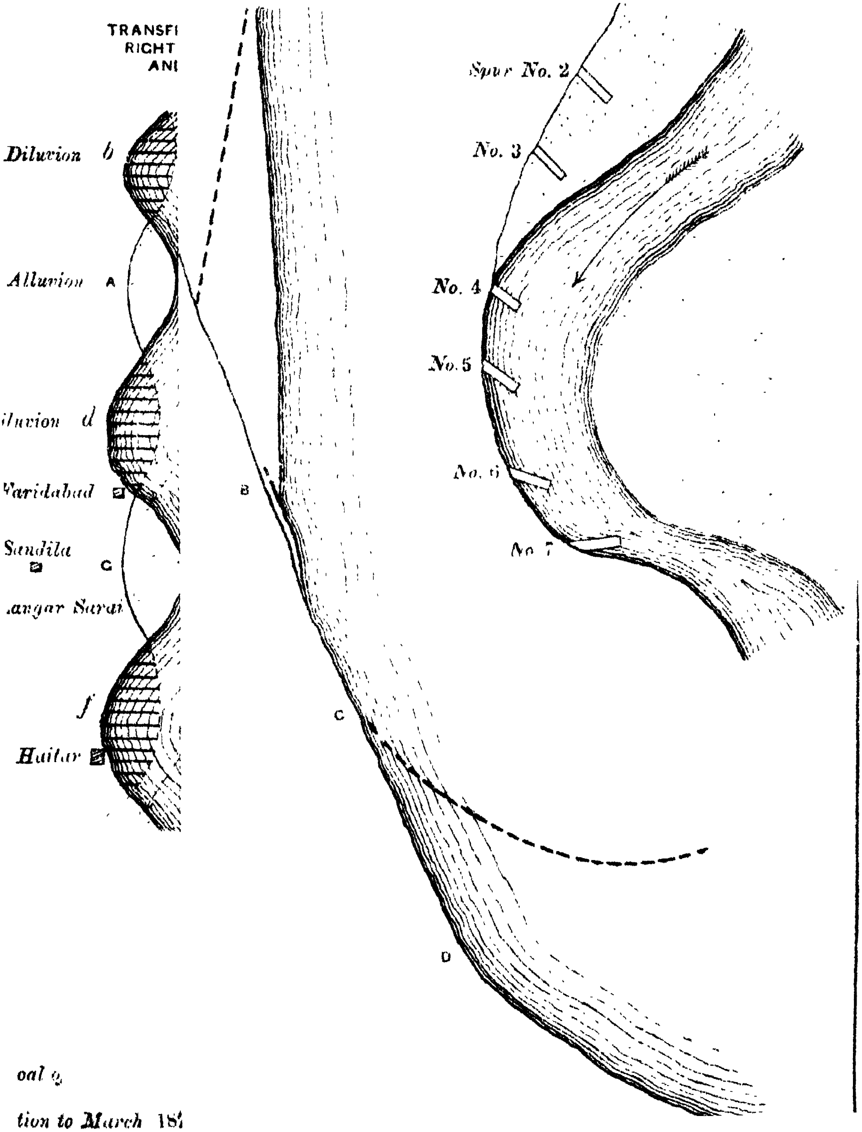
FIG. 1.
TRACE OF THE DEEP STREAM OF THE CHENAB RIVER FOR 50 MILES AS IT WAS IN 1855-56.

Fig. 5.

E OF SURVEY
EQUIRED

Fig. 4.

EROSION AT KHARAK-
WALA, RIVER INDUS,
JANUARY 1879.



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PROFESSIONAL PAPERS

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SECOND

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A. M. B.

CONTENTS.

No. CCCX.

NOTES ON ELEPHANTS AND THEIR TRANSPORT BY RAILWAY.

[*Vide* Plates I. to IV.]

BY CAPT. H. WILBERFORCE CLARKE, R.E., *Offg. Deputy Consulting Engineer for Guaranteed Railways.*

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Act VI. of 1879, by the Governor General in Council, for the preserving of the Indian Elephant.

In this Note, an attempt has been made to gather into one compass all that has been published about the Indian elephant.

I have not entered upon—

the method of capturing them, well told by Sir Emerson Tennent in his work on Ceylon, and by Mr. Sanderson in his "Thirteen years with the Wild Beasts of India,"

as the subject is foreign to the purpose of this paper.

Nor have I gone far—

into the treatment of the diseases of the elephant,

as the subject seems to be chaotic and empirical.

Since Assistant Surgeon W. Gilchrist wrote his treatise on the diseases of the elephant in 1841 to 1846, no scientific attention seems to have been paid to the subject. Major Hawkes, in his "Diseases of the Elephant and Camel," simply condenses and reprints in 1872 the original treatise of 1841.

There seems to be room for great improvement in this branch of knowledge.

If even the nomenclature were improved, something would be done towards further research. In some instances the plants, named as remedies, cannot be recognised, so arbitrary and whimsical is the spelling.

As far as possible, I have corrected the spelling of all the terms used.

A cursory glance will show that the most contradictory opinions are held about matters which should be beyond doubt. From an economic point of view, ignorance regarding such a costly animal is very costly, as from it arise—

(*a*) invaliding of the animals for long periods of time ;
(*b*) high mortality.

If a committee were appointed to consider and to publish a report upon the elephant, in every aspect, much good would accrue.

In this Note, weight should be specially given to statements made by—

Sir Emerson Tennent in 1860 ;
Mr. Sanderson in 1878.

From the—

'Ain-i-Akbari.

This wonderful animal is in bulk and strength like a mountain, and in courage and ferocity like a lion.* He adds materially to the pomp of a king and to the success of a conqueror, and is of the greatest use to the army. Experienced men of Hindústán put the value of a good elephant equal to five hundred horse ; and believe that, when guided by a few bold men armed with matchlocks, such an elephant alone is

* The elephant being essentially a native's animal, the information given by Shaikh Abú-l-Fazl is especially interesting. See page 270 of this Note.

worth double that number. In vehemence on one hand, and submissiveness to the reins on the other, the elephant is like an Arab; whilst in point of obedience and attentiveness to even the slightest signs, he resembles an intelligent human being. In restiveness when full-blooded, and in vindictiveness, he surpasses man. An elephant never hurts the female, though she be the cause of his captivity; never fights with young elephants, nor thinks it proper to punish them. From a sense of gratitude, he never does his keepers harm, nor throws dust over his body, when he is mounted, though he often does so at other times. Once an elephant, during the rutting season, was fighting with another. When he was in the height of excitement a small elephant came in his way; he kindly lifted the small one with his trunk, set him aside, and then renewed the combat. If a male elephant breaks loose during the rutting season, in order to have his own way, few people have the courage to approach him; and some bold and experienced man will have to get on a female elephant, and try to get near him and tie a rope round his foot. Female elephants, when mourning the loss of a young one, will often abstain from food and drink; and sometimes even die from grief.

The elephant can be taught various feats. He learns to remember such melodies as can only be remembered by people acquainted with music; moves his limbs to keep time; exhibits his skill in various ways; shoots off an arrow from a bow, discharges a matchlock, and learns to pick up things that have been dropped, and to hand them over to the keeper. He sometimes gets grain wrapped in hay to eat; this he hides in the side of his mouth, and gives back to the keeper, when he is alone with him.

The teats and womb of a female elephant resemble those of woman; the tongue is round like that of a parrot; the testicles are not visible. Elephants frequently with their trunks take water out of their stomachs, and sprinkle themselves with it. Such water has no offensive smell. They also take out of their stomach grass on the second day, without its having undergone any change.

The price of an elephant varies from a hundred thousand to a hundred rupees*; elephants worth five thousand and ten thousand rupees are fairly common.

There are four kinds of elephants—

1. ***Bhaddar.*** It is well proportioned, has an erect head, a broad chest, large ears, a long tail, and is bold, and can bear fatigue. They take out of his forehead an excrescence resembling a large pearl, which they call in Hindi *Gaj manik.*† Many properties are ascribed to it.

2. ***Mand.*** It is black, has yellow eyes, a uniformly sized belly, a long penis, and is wild and ungovernable.

3. ***Mirg.*** It has a whitish skin, with black spots; the colour of its eyes is a mixture of red, yellow, black, and white.

4. ***Mir.*** It has a small head; obeys readily; and gets frightened when it thunders.

From a mixture of these four kinds are formed others of different names and properties. The colour of the skin of elephants is threefold: white, black, grey. Again, according to the threefold division of the dispositions assigned by the Hindús to the mind, namely, *sat* benevolence, *raj* love of sensual enjoyment, and *tam* irasci-

* During the reigns of Akbar's successor, the price of a well-trained war elephant rose much higher. *Vide* Tuzuk-i-Jahán-gírí, p. 198. At the time of Sháhjahán, the first white elephant was brought from Pégú, *Padishahnama*, I, p. 267. See page 273 of this Note.

† This excrescence is also called *Gajmoti*, or *elephants' pearl*. Forbes has, also, *Gajmanik*, and the *oti*, gaj wati.

bility, elephants are divided into three classes. *First*, such in which *sat* predominates. They are well proportioned, good looking, eat moderately, are very submissive, do not care for intercourse with the female, and live to a very old age. *Secondly*, such in whose disposition *raj* prevails. They are savage looking, and proud, bold, ungovernable, and voracious. *Lastly*, such as are full of *tam*. They are self-willed, destructive, and given to sleep and voracity.

The time of gestation of the female is generally eighteen* lunar months. For three months the *fluida germinalia* intermix in the womb of the female; when agitated, the mass looks like quicksilver. Towards the fifth month, the *fluida* settle, and get gelatinous. In the seventh month, they get more solid, and draw to perfection towards the ninth month. In the eleventh, the outline of a body is visible; in the twelfth the veins, bones, hoofs, and hairs, make their appearance; in the thirteenth, the *genitalia* become distinguishable; and in the fifteenth, the process of quickening commences. If the female, during gestation, gets stronger, the fœtus is sure to be a male; but, if weaker, a female. During the sixteenth month, the formation becomes still more perfect, and the life of the fœtus becomes quite distinct; in the seventeenth, there is every chance of a premature birth, on account of the efforts made by the fœtus to move, and in the eighteenth month the young one is born.

According to others, the sperm gets solid in the first month; the eyes, ears, the nose, mouth, and tongue, are formed in the second; the limbs make their appearance in the third; the fœtus grows and gets strong in the fourth; it commences to quicken in the fifth; in the sixth, it gets sense, which appears more marked during the seventh; there is some chance of a miscarriage in the eight; the fœtus grows during the ninth, tenth, and eleventh months, and is born during the twelfth. It will be a male, if the greater part of the sperm came from the male; and a female, if the reverse be the case. If the sperm of both the male and female be equal in quantity, the young one will be a hermaphrodite. The male fœtus lies towards the right side; the female towards the left; the hermaphrodite in the middle.†

Female elephants have often for twelve days a red discharge, after which gestation commences. During that period, they look startled; sprinkle themselves with water and earth; keep ears and tail upwards; go rarely away from the male; rub themselves against him; bend their heads below his tusks, and cannot bear to see another female near him. Sometimes, however, a female shows aversion to intercourse with the male, and must be forced to copulate, when other female elephants, at hearing her noise, will come to her rescue.

In former times, people did not breed elephants, and thought it unlucky; by the command of His Majesty, they now breed a very superior class of elephants, which has removed the old prejudice in the minds of men. *A female elephant has gener-*

* The time is differently given. The Emperor Jahángir says in his Memoirs (p. 130):—During this month, a female elephant in my stables gave birth before my own eyes. I had often expressed the wish to have the time of gestation of the female elephant correctly determined It is now certain that a female birth takes place after sixteen, and a male birth after nineteen, months [the Emperor means evidently *solar* months]; and the process is different from what it is with man, the fœtus being born with the feet foremost. After giving birth, the female at once covers the young one with earth and dust, and continually caresses it, whilst the young one sinks down every moment trying to reach the teats of the mother." *Vide* Lt. Johnstone's remarks on the same subject in the Proceedings of the Asiatic Society of Bengal for May 1868.

† The hermaphrodite, rare in mankind, is not so among animals. See Evolution of Man, by Ernst Haeckell, 1879.

ally one young one, but sometimes two. For five years, the young ones content themselves with the milk of the mother; after that period they begin to eat herbs. In this state they are called *bál;* when ten years old, *pót;* when twenty years old, *bikka;* when thirty years old, *kalbah.* In fact, the animal changes appearance every year, and then gets a new name. When sixty years old, the elephant is full grown.* The skull then looks like two halves of a ball, whilst the ears look like winnowing fans.† White eyes mixed with yellow, black, and red, are looked upon as a sign of excellence. The forehead must be flat without swellings or wrinkles. The trunk is the nose of the animal, and is so long as to touch the ground. With it he takes up food and puts it into the mouth; sucks up water and throws it into the stomach. He has eighteen teeth; sixteen of them are inside the mouth, eight above and eight below, and two are the tusks outside. The latter are one and more yards long, round, shining, very strong, white or sometimes reddish, and straight, the end slightly bent upwards. Some elephants have four tusks. With a view to usefulness, as also to ornament, they cut off the top of the tusks, which grow again. With some elephants they have to cut the tusks annually; with others after two or three years; but they do not like to cut them when an elephant is ninety years old, An elephant is perfect when it is eight *dast* high, nine *dast* long, and ten *dast* round the belly and along the back. Again, nine limbs ought to touch the ground, namely, the fore-feet, the hind-feet, the trunk, the tusks, the penis, and the tail. White spots on the forehead are considered lucky; whilst a thick neck is looked upon as a sign of beauty. Long hairs on and about the ears point to good origin.

Some elephants rut in winter, some in summer, and some in the rains. They are then very fierce; they pull down houses, throw down stone walls, and will lift up with their trunks a horse and his rider. But elephants differ very much in fierceness and boldness.

When they are in heat, a blackish discharge exudes from the soft parts between the ears and the temples, which has a most offensive smell; it is sometimes whitish, mixed with red. They say that elephants have twelve holes in those soft parts, which likewise discharge the offensive fluid. The discharge is abundant in lively animals, but trickles drop by drop in the sluggish. As soon as the discharge stops, the elephant gets fierce and looks grand; in this state he gets the name of *Tafti* or *Sarhari.* When the above discharge exudes from a place a little higher than the soft parts between the ears and the temples, the elephant is called *Singádhál;* and when the fluid trickles from all three places, *Taljór.* When hot, elephants get attached to particular living creatures, as men, or horses; and some to any animal. So at least according to Hindú books.

The *Bhaddar* ruts in Libra and Scorpio; the *Mand* in spring; the *Mirg* in Capricorn and Sagittarius; the *Mir* in any season. Elephant-drivers have a drug which causes an artificial heat; but it often endangers the life of the beast. The noise of battle makes some superior elephants just as fierce as at the rutting season; even a sudden start may have such an effect. Thus His Majesty's‡ elephant *Gaj*

* See pages 253, 261, 266, and 284.

† *Ghalla afshan* is a flat piece of wicker work, from one to two feet square. Three sides of the square are slightly bent upwards. They put grain on it, and seizing the instrument with both hands, throw up the grain, till the refuse collects near the side which is not bent upwards, when it is removed with the hand.

‡ His Majesty here signifies the Emperor Akbar who reigned in Hindústán 1556 to 1605 A.D.

h—he becomes brisk, as soon as he hears the sound of the Imperial drum, or gets the abovementioned discharge. This peculiar heat generally makes its first appearance when elephants have reached the age of thirty; sometimes, however, earlier, at the age of twenty-five. Sometimes the heat lasts for years, and some of the Imperial elephants have continued for five years in uninterrupted alacrity. But it is mostly male elephants that get hot. They then throw up earth, run after a female, roll about in mud, and daub themselves all over with dirt. When hot, they are very irritable, and yawn a great deal, though they sleep but little. At last, they even discontinue eating, and dislike the foot-chain; they try to get loose, and behave noisily.

The elephant, like man, lives to an age of one hundred and twenty years.*

The Hindí language has several words for an elephant, as *hasti gaj, pil, hát'hi*, &c. Under the hands of an experienced keeper, he will much improve, so that his value, in a short time, may rise from one hundred to ten thousand rupees.

The Hindús believe that the eight points of the earth are each guarded by a heavenly being in the shape of an elephant; they have curious legends regarding them. Their names are as follows:—

1. *Airáwata*, in the East.
2. *Pundarika*, South-east.
3. *Báman*, South.
4. *Kumuda*, South-west.
5. *Anjan*, West.
6. *Puhpadanta*, North-west.
7. *Sárbhabhúma*, North.
8. *Supratika*, North-east.

When occasions arise, people read incantations in their names, and address them in worship. They also think that every elephant in the world is the offspring of one of them. Thus, elephants of a white skin and white hairs are related to the first; elephants with a large head, and long hairs, of a fierce and bold temper, and eyelids far apart, belong to the second; such as are good looking, black, and high in the back, are the offspring of the third; if tall, ungovernable, quick in understanding, short-haired, and with red and black eyes, they come from the fourth; if bright black, with one tusk longer than the other, with a white breast and belly, and long and thick fore-feet, from the fifth; if fearful, with prominent veins, with a short hump and ears, and a long trunk, from the sixth; if thin-bellied, red-eyed, and with a long trunk, from the seventh; and if of a combination of the preceding seven qualities, from the eighth.

The Hindús also make the following division into *eight* classes:—

1. Elephants whose skin is not wrinkled, who are never sick, are grand looking, do not run away from the battle-field, dislike meat, and prefer clean food at proper times, are said to be *Dév mizáj* (of a divine temper).

2. Such as possess all the good qualities of elephants, and are quick in learning, in moving the head, ears, trunk, fore-legs, hind-legs, and the tail, and do no one harm, except they be ordered to do so, are *Gandharba mizáj* (angelic).

3. If irritable, of good appetite, and fond of being in water, they are *Barhaman mizáj* (of a brahminical temper).

4. Such as are very strong, in good condition, fond of fighting, and ungovernable, are said to have the temper of a *Khetri*, or warrior.

* Hindústán must, in those days, have been a very healthy country.

5. Those which are of a low stature, and forgetful, self-willed in their own work, and neglectful in that of their master, fond of unclean food, and spiteful towards other elephants, are *Súdra mizáj.*

6. Elephants who remain hot for a long time, and are fond of playing tricks, or destructive, and lose the way, have the temper of a serpent.

7. Such as squint, and are slow to learn, or feign to be hot, have the temper of *pisháca* (spectre).

8. Those who are violent, swift, and do men harm, and fond of running about at night, have the qualities of a *Rárhhas* (demon).

The Hindús have written many books in explanation of these various tempers, as also many treatises on the diseases of the elephants, their causes and proper remedies.*

Elephants are found in the following places: In the Súba of Agra, in the jungles of Bayáwán and Narwar, as far as Barár; in the Súba of Iláhábád in the confines of Panna, (Bhat'h) Ghorá, Ratanpúr, Nandanpúr Sirguja, and Bastar; in the Súba of Málwa, in Handiah, Uchhod, Chanderí, Santwás, Bíjágarh, Ráísín, Hoshangábád, Garha, and Hariágarh; in the Súba of Bihár, about Rohtás and in Jhárk'hand; and in the Súba of Bengal, in Orísá and in Sátgáon. The elephants from Panna are the best.

A herd of elephants is called in Hindí *sahn.* They vary in number; sometimes a herd amounts to a thousand elephants. Wild elephants are very cautious. In winter and summer, they select a proper place, and break down a whole forest near their sleeping-place. For the sake of pleasure, or for food and drink, they often travel great distances. On the journey one runs far in front of the others, like a sentinel; a young female is generally selected for this purpose. When they go to sleep, they send out to the four sides of the sleeping-place pickets of four female elephants, who relieve each other.

Elephants will lift up their young ones, for three or four days after their birth, with their trunks, and put them on their backs, or lay them over their tusks. They also prepare medicines for the females when they are sick or in labour-pains, and crowd round about them. When some of them get caught, the female elephants break through the nets, and pull down the elephant-drivers. And when a young elephant falls into a snare, they hide themselves in an ambush, go at night to the place where the young one is, set it at liberty, and trample the hunters to death. Sometimes its mother slowly approaches alone, and frees it in some clever way. I have heard the following story from His Majesty:—"Once a wild young one had fallen into a pit. As night had approached, we did not care to pull it out immediately, and left it; but when we came next morning near theplace, we saw that some wild elephants had filled the pit with broken logs and grass, and thus pulled out the young one." Again, "Once a female elephant played us a trick. She feigned to be dead. We passed her, and went onwards; but when we returned at night, we saw no trace of her."

The Harness of the Elephant.

1. The *Dharnah* is a large chain of iron, gold, or silver,—of sixty oval links, each weighing three sirs; but it differs in length and thickness according to the strength

e should be searched for and examined.

of the elephant. One end is fixed in the ground, or fastened to a pillar, the other tied to the left hind-leg of the elephant. Formerly, they fastened this chain to the fore-foot; but as this is injurious to the chest of the elephant, His Majesty ordered the usage to be discontinued.

2. The *Andú* is a chain with which both fore-feet are tied. As it annoys the elephant, His Majesty ordered it to be discontinued.

3. The *Beri* is a chain for fastening both hind-feet.

4. The *Baland* is a fetter for the hind-feet,—an invention of His Majesty. It allows the elephant to walk, but prevents him from running.

5. The *Gaddh beri* resembles the Andú, and is an additional chain for the hind-legs of unruly and swift elephants.

6. The *Loh langar* is a long chain, suitable for an elephant. One end is tied to the right fore-foot, and the other to a thick log, a yard in length. This the driver keeps near him, and drops it, when the elephant runs two swiftly, or gets so unruly as no longer to obey. The chain twists round his leg, and the log will annoy the animal to such an extent, that he necessarily stops. This useful invention, which has saved many lives, and protected huts and walls, is likewise due to His Majesty.

7. The *Churkhi* is a piece of hollowed bamboo, half a yard and two tassújes long, and has a hole in the middle. It is covered with sinews and filled with gunpowder, an earthen partition dividing the powder into two halves. A fuzee wrapt in paper is put into each end. Fixed into the hole of the bamboo at right angles is a stick, which serves as a handle. Upon fire being put to both ends, it turns round, and makes a frightful noise. When elephants fight with each other, or are otherwise unruly, a bold man on foot takes the burning bamboo into his hand, and holds it before the animals, when they will get quiet. Formerly, in order to separate two elephants that were fighting, they used to light a fire; but people had much trouble, as it seldom had the desired effect. His Majesty invented the present method, which was hailed by all.

8. *Andhiyári* (darkness), a name which His Majesty changed into *Ujyáli* (light), is a piece of canvass above one and a half yards square. It is made of brocade, velvet, &c., and tied at two ends to the *Kiláwa.* When the elephant is unruly, it is let fall, so that he cannot see. This has been the saving of many. As it often gives way, especially when the elephant is very wild, His Majesty had three heavy bells attached to the ends of the canvass, to keep it better down. This completed the arrangement.

9. The *Kiláwa* consists of a few twisted ropes, about one and a half yards long. They are laid at the side of each other, without, however, being interwoven among themselves, the whole being about eight fingers broad. A ring is drawn through both ends of the ropes, and fastened where the throat of the elephant is: the elephant driver rests his feet in it, and thus sits firmly. Sometimes it is made of silk or leather. Others fix small pointed iron spikes to the kiláwa, which will prevent an unruly elephant from throwing down the driver by shaking his head.

10. The *Dult'hi* is a rope five yards long, as thick as a stick. This they tie over the kiláwa, to strengthen it.

11. The *Kanár* is a small pointed spike, half a yard long. This they likewise attach to the kiláwa, and they prick the elephant's ears with it, in order to make the animal wild, or to urge it on.

12. The *Dór* is a thick rope passing from the tail to the throat. When properly

tied, it is an ornament. They catch hold of it when the elephant makes an awkward movement; and attach many trappings to it.

13. The *Gadela* is a cushion put on the back of the elephant, below the dult'hi. It prevents galling, and is a source of comfort.

14. The *Guduṇṭi* is a chain of brass. They attach it near the tail, which it prevents from getting injured by the dult'hi. It is also ornamental.

15. The *Pichwah* is a belt made of ropes, fastened over the buttocks of the elephant. It is a support for the *Bhoi*, and of much use to him in firing.

16. The *Chaurási* consists of a number of bells attached to a piece of broadcloth, tied on before and behind with a string passed through it. It looks ornamental and grand.

17. *Pitkachh* is the name of two chains fastened over the elephant's sides. Attached to them, a bell hangs below the belly. It is of great beauty and grandeur.

18 *Large chains.* They attach six on both sides, and three to the kiláwa, the latter being added by His Majesty.

19. *Kuṭás* (the tail of the Thibetan yak). Sixty, more or less, are attached to the tusk, the forehead, the throat, and the neck. They are either white, black, or pied and look very ornamental.

20. The *Ṭayyá* consists of five iron plates, each a span long, and four fingers broad, fastened to each other by rings. On both sides of the Tayyá there are two chains, each a yard long, one of which passes from above the ear, and the other from below it, to the kiláwa, to which both are attached. Between them is another chain, which is passed over the head and tied to the kiláwa; and below, crossways, are four iron spikes ending in a curve, and adorned with knobs. The *Kuṭás* are attached here. At their lower end are three other chains similarly arranged Besides, four other chains are attached to the knob; two of them, like the first, end in a knob, whilst the remaining two are tied to the tusks. To this knob again three chains are attached, two of which are tied round about the trunk, the middle one hanging down. *Kuṭás* and daggers are attached to the former knobs, but the latter lies over the forehead. All this is partly for ornament, partly to frighten other animals.

21. The *Pák'har* is like armour, and of steel; there are separate pieces for the head and the trunk.

22. The *Gaj-jhamp* is a covering put as an ornament above the *pák'har.* It looks grand, and is made of three folds of canvass, put together and sewn, broad ribbons being attached to the outside.

23. The *Meg'h dambar* is an awning, to shade the elephant-driver, an invention by His Majesty. It also looks ornamental.

24. The *Rampiyala* is a fillet for the forehead, made of brocade or similar stuffs, from the hem of which nice ribbons and *kuṭás* hang down.

25. The *Gateli* consists of four links joined together, with three above them, and two others over the latter. It is attached to the feet of the elephant. Its sound is very effective.

26. The *Pái ranjan* consists of several bells similarly arranged.

27. The *A'nkús* is a small crook. His Majesty calls it *Gajbág.* It is used for guiding the elephant and stopping him.

28. The *Gaḍ* is a spear which has two prongs, instead of an iron point. The Bhoí makes use of it, when the elephant is refractory.

29. The *Bangrí* is a collection of rings made of iron or brass. The rings are put on the tusks, and serve to strengthen as well as to ornament them.

30. The *Jagawaṭ* resembles the *Gaḍ*, and is a cubit long. The Bhoí uses it, to quicken the speed of the elephant.

31. The *Jhanḍá*, or flag, is hung round with *kuṭás* like a *togh*. It is fixed to the side of the elephant.

But it is impossible to describe all the ornamental trappings of elephants.

For each *Mast* and *Shírgir* and *Sáda* elephant, seven pieces of cotton cloth are annually allowed, each at a price of 8¼ *dáms*. Also, four coarse woollen pieces, called in Hindí *kambal*, at 10 *dáms* each, and eight ox hides, each at 8 *dáms*. For *Manjholá* and *Karha* elephants, four of the first, three of the second, and seven of the third, are allowed. For *P'handurkiyas*, and *Mokals*, and female elephants, three of the first, two of the second, four of the third. The saddle cloth is made of cloth, lining, and stuff for edging it round about; for sewing half a sír of cotton-thread is allowed. For every *man* of grain, the *halka dár* is allowed ten *sírs* of iron for chains, &c., at 2 *dáms per sír*; and for every hide, one *sír* of sesame oil, at 60 *dáms per man*. Also, 5 *sírs* coarse cotton-thread for the *kiláwa* of the elephant on which the *Faujdár* rides, at 8 *dáms per sír*; but for other elephants, the men have to make one of leather, &c., at their own expense.

A sum of 12 dáms is annually subtracted from the servants; but they get the worn-out articles.

In order to prevent laziness, and to ensure attentiveness, His Majesty, as for all other departments, has fixed a list of fines. On the death of a male or female *khássa* elephant, the *Bhoís* are fined three months' wages. If any part of the harness is lost, the Bhoís and Met'hs are fined two-thirds of the value of the article; but in the case of a saddle cloth, the full price. When a female elephant dies from starvation, or through want of care, the Bhoís have to pay the cost price of the animal.

If a driver mixes drugs with the food of an elephant, to make the animal hot, and it dies in consequence thereof, he is liable to capital punishment, or to have a hand cut off, or to be sold as a slave. If it was a *khássa* elephant, the Bhoís lose three months' pay, and are further suspended for one year.

Two experienced men are monthly despatched to enquire into the fatness or leanness of *khássa* elephants. If elephants are found by them out of flesh, to the extent of a quarter, according to the scale fixed by the *Págosht* Regulation, the grandees in charge are fined, and the Bhoís are likewise liable to lose a month's wages. In the case of *Halka* elephants, Ahadís are told off to examine them, and submit a report to His Majesty. If an elephant dies, the *Maháwat* and the *Bhoi* are fined three months' wages. If part of an elephant's tusk is broken and the injury reaches as far as the *kali*—this is a place at the root of the tusks, which on being injured is apt to fester, when the tusks get hollow and become useless—a fine amounting to one-eighth of the price of the elephant is exacted, the Dárogha paying two-thirds, and the Faujdár one-third. Should the injury not reach as far as the *kali*, the fine is only one-half of the former, but the proportions are the same. But, at present, a fine of one *per cent.* has become usual; in the case of *khássa* elephants, however, such punishment is inflicted as His Majesty may please to direct.

The following table (page 252*a*) gives details regarding the classification of elephants and the pay of their attendants:—

From the Commissariat Code for the Madras Presidency, by Major H. P. Hawkes, D.A.C.G., 1878, *paragraphs* 335, 346 *to* 354, 380 *and* 608.

Elephants should not be purchased less than 15, more than 30, years old, nor less than 7 feet in height; they will work until 80 years old.

The age is roughly judged by the overturning of the upper lap of the ear. The elephant is supposed to be—

30 years old, when the ear is turned over 1 inch.
30—60 „ „ „ 1 to 2 inches.
Aged, when the ear is turned over more than 3 inches.

When wading, or swimming in, rivers, the load should be removed. The ivory obtained from periodical cuttings of elephants' tusks and from dead elephants is brought on the general stock.

When an elephant dies, an application should be made to the Officer Commanding the Station to assemble a committee to report on the cause of death. The proceedings should be handed to the Commissariat Officer.

The following table gives details regarding the daily food of an elephant:—

Elephants carry	*Ration, per diem in lbs. on land.*						*Ration, per diem in lbs. at sea.*					*Attendants on each elephant.*	
	Rice.	Gingely oil.	Salt.	Forage, green.	Or forage, dry.	Water, gallons.	Rice or flour.	Salt.	Forage, green.	Or forage, dry.	Water, gallons.	At Rs. 9.	At Rs. 6.
7 bullocks' loads = 861 lbs.	30	$\frac{1}{8}$	$\frac{3}{16}$	250	125	30	18 to	$\frac{5}{32}$	320	170	45	1	1
6 „ „ = 738 „	25	...	...	...	...	...	20	...	...	...	...	...	...
5 „ „ = 615 „	20	...	...	...	...	...	...	...	...	...	...	...	...

Rice and salt (rations) are not issued to sick elephants.* Should forage, in excess of the allowance, be required for elephants of unusual size, special sanction of the Commissary General must be obtained. An elephant drinks twice daily 15† gallons; he cannot go more than 24 hours without water. When he dies, his two attendants are dismissed; and when laid up with galled back, wounds, sprains (caused by neglect), are put on half-pay till the animal is fit for work. A purge should be given

* *See* page 258, 280, 284, and 288.
† Dr. Gilchrist says 24 gallons on each occasion.

15 days before going on boardship; and a certain quantity of* earth, which acts as a purge, should be taken.

A faujdár in charge of a detachment of elephants numbering—

8 to 9	is allowed	Rs.	16	per month.
10 to 12	„	„	18	„
13 to 15	„	„	20	„

Elephant-gear consists of—

A namda of felted wool, 1 inch thick, 6 feet to 7½ feet square, covered on the upper side with gunny, and on the lower with coarse cloth.

A gadela, or two bags of gunny, each 1 foot thick, 2½ feet broad, 5 feet to 6 feet long (when empty).

These bags are filled with bullrushes and joined together at each end, leaving the middle space open to receive the backbone.

A ním-gaddi of the same dimensions as the gadela, save in the width, which is less.

A jhúl, or cloth of gunny, 10 feet to 12 feet long, and 6 feet to 7 feet wide, the kiláwa, or neck-rope, 12 feet long, ¾-inch in diameter, weighing 2 lbs. This rope is passed twice round the animal's neck.

A nanda, or girth-rope, 90 feet long, 1½-inch in diameter, weighing 10 lbs. covered at those parts, where it passes beneath the belly and tail, with leather. This secures the saddle.

A load-rope, 60 feet long, 1 inch in diameter, weighing 5 lbs. This secures the load.

A rice-bag, which holds the rice-ration, 30 lbs.

An undher, or a pair of fetters, for hobbling.

A lunga, or a pair of tethering chains.

The following table shows the quantity of material required for elephant-housings:—

Elephants of	Yards of gunny 9 inches wide for— Jhúl.	Gadela.	Nim-gaddi.	Namda.	Rice-bag.	Total.	For a namda. Dingari, 40 inches wide.	Wool, or coir.	Cotton thread.	Rushes for stuffing.	Bullock-hide, for edging namda	Hemp, or twine, for sewing.	Hemp for ropes.
							Yards.	lbs.	lbs.	lbs.			lbs.
The 1st size, ...	37	25	14	18	6	100	60	14	¾	62	1	20	17
The 2nd size, ...	33	22	11	16	6	88	51	12	...	60	½	12	...

* Dr. Gilchrist says siliceous earth; but Mr. Sanderson, black earth impregnated with natron.

When required for pushing guns, the elephant's head should be protected with a well-stuffed leather pad. Foot-boards required for the conveyance of sick, in howdas are supplied by the Commissariat.

From the Record of the Expedition to Abyssinia, by Major Holland and Captain Hozier, 1870, *Vol.* 1, *pages* 86, 214, 226, *and* 360; *Vol.* 2, *pages* 172, 229, 263, *and* 472.

Elephants travelled many hundreds of miles, over a mountainous country, bearing the loads set forth in the following table:—

12-pr. B. L. Armstrong guns.	*Weight in lbs.* Detail.	Total.	No. of elephants required.	8-inch Mortar.	*Weight in lbs.* Detail.	Total.	No. of elephants required.
Gun, ...	924			Mortar, ...	924		
Cradle, ...	150			Travelling bed,..	168		
Pad, ...	500			Cradle, ...	252		
		1,574	1	Pad, ...	500		
						1,844	1
Carriage, ...	966						
Cradle, ...	150			Iron bed, ..	840		
Pad, ...	500			Travelling bed,..	168		
		1,616	1	Cradle, ...	252		
				Pad, ...	500		
						1,760	1
2 boxes ammunition,	510						
1 wheel, ...	314						
Pad, ...	500			Skids, ...	..		
		1,324	1	Implement boxes,	..		
				Handspikes, ..	..		
						?	1
3 wheels, ...	942						
Pad, ...	500						
		1,442	1	Powder,.. ..	..	?	1

The mortar-shells were carried on mules,—4 to each mule.

The loading of the 12-pr. B. L. Armstrong gun was thus effected—

It being difficult to get the animals to remain quite under the fall, it was found impracticable to use the shears. The loading was therefore effected as follows:—

In the case of the gun, a skid was placed with one end resting on the ground, the other on the cradle, the elephant being in a sitting posture. The breech-screw being removed, handspikes were inserted in the bore at the breech on the muzzle, and the gun was lifted up along the spar by eight men to its rest in the cradle. To assist the lift, a siding-rope was attached to the gun at the trunnions, passed over the cradle, and manned on the opposite side by four men; with this too, the gun was kept steady, while the men, who were lifting, obtained a fresh purchase.

In the case of the carriage, two skids were used; twelve men were required to lift it.

The limber was lifted bodily up and placed in its cradle; a wheel was placed on the top and lashed securely. The ammunition-boxes were slung, one on each side of the animal, with a wheel laid on the top of the pad, and lashed.

The three wheels were slung,—one on each side, and one on the top.

The chief delay took place in equipping the elephants with their gear and cradles; once this was done, the gun and carriage were loaded in two or three minutes. The other loads took longer on account of the lashing.

The loading of the 8-inch mortars was thus effected:—

The elephants being seated, two parallel skids were placed with their upper ends resting on the cradle, their lower ends on the ground, parallelism being preserved by iron stays; they were formed with a track, along which the iron trucks of the traveling bed, fitted with iron flanges, ran.

Tackle was attached to the travelling bed passed over rollers, which were fixed in the cradle and manned on the opposite side of the animal; four men, with hand-spikes, heaved the mortar (or bed) up the skid, and the tackle being hauled on, the load was run up rapidly into its cradle.

To prevent the pad being displaced while the load was hauled up, a third skid was placed on the off (hauling) side with one end resting against the cradle.

The delay in preparing the elephant was the same as in the case of the gun.

Unloading was performed, under the same arrangements, with both descriptions of ordnance; with the guns, it was an easier process than that of loading, and often only one skid was used in unloading the gun-carriage.

In place of coir, curled hair should be used for the stuffing of the under-pad, which also should be thicker.

The skin of the elephant is so tender that it easily becomes chafed. Serious galls and sores ensued from friction as well as from the pressure of the heavy weights, which remained on the elephants' backs, at times from 12 to 20 hours without relief.

The pads should be fitted with breechings and breast-pieces, as the rope causes very severe galls and sores. Moreover, in ascending, the strain caused by the weight being thrown back, acts very detrimentally on the respiration. To remedy this defect, an arrangement like a horse-collar might be used.

They should be attached and secured in the same manner as the cradles: that is, by being secured from the sides under the belly, instead of by a rope passing completely round and over the animal.

The objection to the present arrangement is that, if the ropes are found to be loose, they cannot be adjusted without removing the loads;

but, under that proposed, the ropes could be drawn tight as the girths of a saddle.

Elephants are slow movers over a mountainous country, and apt to get foot-sore. They have frequently been employed for the draft-transport of artillery in Indian warfare; but, when guns have been carried, it has been for short distances only. In Abyssinia it was proved that elephants could carry 12-pr. B. L. Armstrong guns and 8-inch mortars over steep mountains for many hundreds of miles.

The following table shows the daily allowance at sea and on land: —

No. of elephants.	*Daily Allowance in lbs. per each Elephant.*								
	At sea					*On land.*			
	Gram.	Rice or flour.	Hay or karbi.	Salt.	Water.	Flour.	Hay.	Firewood	Salt.
44	4	20	175	$\frac{5}{32}$	40 gallons.	25	175	15	$\frac{1}{8}$

Of these forty-four elephants, five died after the fall of Magdāla; two from exhaustion, and three from want of water.

Two ships were fitted for carrying elephants from India to Abyssinia—

The elephants were placed in the hold* of the vessels on a temporary flooring made of stones and shingle, back to back; their heads towards the ship's sides. A vessel of 34 or 36 feet beam admits of two elephants being thus placed, and of a gang-way being left between, broad enough for the attendants to pass to and fro for clearing away filth.

The breadth of the stalls was 6 feet divided off by two cross-beams, each 1 foot broad, $\frac{3}{8}$ foot thick, which rested on a longitudinal shelf-piece, $\frac{3}{8}$ foot broad, $\frac{3}{4}$ foot thick, which again was secured to the ship's side by cleats $1\frac{1}{8}$ foot long, $\frac{7}{12}$ foot wide, placed $5\frac{5}{12}$ feet apart along the side.

These transverse beams required a strong moveable upright in the centre (amidship) to prevent their being injured, or displaced, by the elephants pressing against them.

The following details regarding the nature of the elephant may be of service: —

The skin should be of a colour approaching to black, and its feel bristly. A pale coloured elephant with the hair downy is not in good health.

In good health an elephant is always in motion, swinging the well-stretched trunk, and flapping the ears; a listless state, with trunk gathered up, betokens ill-health.

The inside of the mouth and the tongue should be of a rich pink colour, without any black spots on the palate or roof of the mouth.

* See page 260.

The light spots on the head of the trunk, and neck, and ears, should show bloom; they are the complexion of the animal, or beauty-spots. Too pale a colour denotes poorness of health; and too high a colour, an overheated state of body.

The eye of an elephant in good health should appear as large in the evening, as in the strong light of the morning. When an elephant becomes overheated in blood, his eye will be covered by a scum difficult to remove. Fresh butter, or good ghi, with the rations is as good as anything for them in this state.

Hard lumps on the belly, or round the flanks, are of two kinds:—

In the first case the lumps will break off themselves, and are the effect of an overheated state of body throwing itself off in superficial eruption. This is not dangerous.

In the second, the lumps are hard and will not break; they are the precursors of "zahr-bád"; and if the disease be not nipped in the bud, it will destroy the animal.

The male becomes *must* during the rainy season for a period of three months. This season may be shortened by cooling medicines. He will, in this state, have a discharge of water from two small orifices, at each side of the jaw and under the eye.

The parts inside and under the nails are liable to sores; and so tender does the foot become, that pressure of a finger on the spot will make the animal wince. This disease called "kandi" will (if the sore gets no vent downwards) cause the nail to fall off. It is a troublesome disease, and takes months to cure. In perfect health, a moisture, or perspiration, may be noticed at the junction of the toe-nail with the flesh of the foot.

Elephants troubled with worms eat mud; they should then go rationless.* If this occurs oftener than once a month, it is a proof that the mixtures of food are not suitable. A good elephant-driver will pay great attention to the dung, urine, thirsty or unthirsty state of the animal. Elephants, rationless, in this state, are considerably purged by the earth they eat.

To stop purging, bamboo-leaves should be given; and the animals should not be bathed. Tumours and skin-cuts are invariably caused by negligence, or ignorance, on the part of the drivers. After loading their elephants, the drivers will often displace part of the load to stowing privately some bundle of their own property; sometimes the insufficient stuffing of the pads accounts for the mischief.

Treatment.—When a tumour is discovered, a driver will generally counsel its being pressed away; this will cause sinuses to run deeper into the skin.

Apply a poultice of ním-leaves for two or more days, till the skin becomes soft, and the tumour rises near the surface; then rip it open freely, cutting it on either side down the ribs, but never across the back-bone.

After the pus has escaped, there are two modes of dealing with the wound—

(*a*). Put pigeon-dung and salt (or bark of the root of the madder tree and salt) in equal proportions into the sore for a few days after being cut open, to clear away any proud flesh, and keep the wound warm by a bit of padded stuff.

Then apply an oinment consisting of—

$\frac{2}{3}$ bottle of native sweet oil,
$\frac{1}{3}$ „ spirits of turpentine,
4 ounces of clean, good camphor.

* The mud causes the worms to be evacuated dead. The word *ration* applies to the allowance of salt, rice and flour.

There is no better ointment* than this for curing elephant-sores.

(*b*). Fill up the wound with ním-leaves after bruising them in a small quantity of hot water; remove this plugging twice a day for three days; and syringe out with a decoction of blue vitriol, until the wound assumes a healthy appearance.

Gunda-birosa may then be applied, care being taken that the lips of the wound are kept open, and that the granulation fills up from the bottom.

Abrasions require to be washed clean and smeared with camphor-oil (or carbolic acid) to prevent annoyance from flies. Take the animal off work, and such sores will soon heal.

In the case of sore-toes, or feet, clear the vicinity of the sore; wash it well with a decoction of blue vitriol, forcibly squirted with syringe, till the offensive smell be overcome; then apply—

Chloride of lime, 2 chhatáks = 4 ounces.
Common lime, 4 „ = 8 „

Mix both into a paste, and plaster the wound, which must be closed with cotton to prevent intrusion of dirt. The same may be applied to whitlows, or chajún sores.

In the case of sore eyes, use caustic lotion with a syringe, whenever there is inflammation present For a white film, syringe the eye with a solution of half of an ounce of alum in a pint of water.

Elephants in a heated state are apt to get a chill, "chaurang." Extreme cold has the same effect. The sinews of the neck, chest, and hips become cramped, and the animal can barely move. A dram of liquor, or a few warm "masálih" may prevent the disease; but months of care will hardly cure it, and the animal will, in future, be predisposed to it.

The following are the chief causes of disease:—

Want of shelter from extreme heat and cold; excessive rain and storms of wind and rain; want of sleep; violence in the use of the "áukús" which induces a running of the eyes, turning into sore eyes; heating fodder, which also produces sore eyes; bark and leaves, covered with birds' dung, which produces spasms; the giving of gram when they are suffering from worms; exposure to the sun, which causes "sarza," in which a tremor comes over the animal and he expires; neglect of elephant attendants as to food, which should be clean, wholesome, and sufficient; the not being bathed daily during the hot season; overwork and bad driving.

Elephants require but little sleep. When he has had enough to eat, and is not prevented by noise, want of room, or uneven ground, he will lie down before midnight; sleep for a couple of hours; get up and eat a little, and then lie down on the other side, rising finally two or three hours before daylight to finish his fodder. It takes a considerable time for him to satisfy the first cravings of hunger; and if the fodder be not given in time to enable him to do so by midnight, he will go on eating all night, and not lie down at all.

* Sergeant Russell, Commissariat Department, says—
1 part carbolic acid,
3 parts common oil,
is the best ointment.

The practice of Government elephant-drivers on the march is this—

After the march, the elephant is tied to a tree ; and his fore-legs being fastened together, he is left in the sun, while the elephant-driver eats, smokes, and sleeps, till he thinks it is cool enough to take his animal for fodder that is brought in late in the evening. Then the animal is bathed, so that, with this and that, he does not begin eating his fodder till 8 or 9 o'clock. He then eats voraciously till the camp is awake again. If this does not kill him directly, it so weakens him, that he is unfit for any real work.

An elephant should go one hour after the march for fodder ; be well washed ; get, before sunset, a little fodder ; and then the gram ; and be fastened for the night, with the night's fodder before him, at 7 o'clock. He seldom sleeps more than four hours, though after great fatigue he will lie all night. Early feeding should be insisted on.

Attention should be paid to giving elephants fodder enough. No amount of gram will compensate for a continued short allowance of good fodder ; he requires a belly-full of fodder, more even than the horse. The fodder consists of—

Green chanā, gular, banian, bargul, jack-tree, plantain, sugar-cane, pípul, pakur, semal, ammā, permi, dried dhān, narkat, grass of all kinds, bamboo, kurean kāns, dhān, jowar, mundwā, ooreed, and dāl.

Pípul should be given moderately and cautiously, for it is heating, and causes an affection of the eye.

From the Transport Regulations, Transport of Troops by Sea, 1878, *paragraphs* 36, 39, 89, 131, *and* 183.

When elephants are shipped, the deck on which they are placed cannot be too well ventilated. Windsails should be fixed wherever practicable.

Scuppers (fitted with a 4-inch pipe) should be cut in the deck, in rear of the stalls, to carry into the bilge the urine and water used in cleaning the stalls ; placed wherever the water lies, two or three on each side of the vessel ; and covered thus $\begin{pmatrix} + & + \\ + & + \end{pmatrix}$, not with "roses."

Elephants (one fore-leg and both hind-legs tethered) are usually placed in the hold,* as they feel the motion less there, part of the planking of the upper deck being removed for the purpose of ventilation. If the bottom of the hold be not boarded, shingle, 2 or 3 feet in depth, should be laid with a covering of sand. In this case, 3 tons of sand, per elephant, per period of 30 days, should be taken to allow of the old polluted sand being daily replaced with fresh clean sand, and to keep the elephant's feet dry

* Sergeant Russell, Commissariat Department, says—

That he embarked eighty elephants at Calcutta, for Chittagong, for the Looshai expedition, on the *deck* of vessels belonging to the British India Steam Navigation Company ; and four elephants, for the Khediv of Egypt, on the *deck* of a steamer of the P. and O. Line.

and uninjured. Care must be taken to prevent the pumps getting choked.*

A spare berth, amidships, should be left for a sick elephant. This allows of a dead elephant being easily removed; if it be not done, the dead elephant has to be cut up. This is an operation not only disagreeable, but one that excites the other elephants. *See Plate* III.

From the Soldier's Pocket-book for Field Service, by Colonel Sir Garnet Wolseley, pages 37, 271, *and* 272.

The elephant becomes fit for work at 20 years of age, lasts well to 50 or 60 years of age; can, when laden, keep up well with infantry; is most tractable in disposition; is invaluable during marches, in countries flooded by rain, for extracting carts, guns, and wagons that have stuck in the mud; is used in India for the draught of siege-train guns.

Before taking the guns under fire, it is necessary to have the elephants taken out and replaced by bullocks.†

The height of an elephant varies from 10 to 11 feet‡; his weight is about 6,600 lbs.; a height of 15 feet should be left on bridges, where the trusses are joined transversely overhead. Elephants cannot be made to crowd together.

11′ × 9′	= 99 sqr. feet,	the space occupied by a laden elephant.
11′ × 5′	= 55 ,,	,, ,, an unladen elephant.
13 cwt.	=	average load of an elephant.
72 ,,	=	gross load of animal and its burden.
28·8 ,,	=	load on the two hind-legs = $\frac{4}{10}$ of
43·2 ,,	=	,, ,, fore ,, = $\frac{6}{10}$
44·0 ,,	=	possible maximum load, on one foot.
66·0 ,,	=	weight of an elephant harnessed to a gun.
6·5 feet	=	distance between the fore and hind-legs.
5·5 ,,	=	distance of the hind-legs of the shaft-elephant from the axle of the limber.
22·5 ,,	=	distance of the hind-legs of the leader-elephant from the axle of the limber.

From the Hand-book for Field Service, by General Lefroy, pages 50 *to* 52 *and* 426.

The elephant draws a gun over narrow ravines where the space is so

* This practice seems to be fraught with danger. How are the pumps to be kept clear of the sand? If clay were taken, the pumps would not be choked; and the clay might be useful as a deodoriser. On the use of siliceous earth, *see* page 288; and, on black earth, page 268.

† It is elsewhere stated that this is unnecessary.

‡ This is entirely opposed to what is said by Mr. Sanderson, the latest authority. *See* page 264.

restricted that a team of horses or bullocks would be unable to act, and manual labour would have to be employed,—or in a heavy, sandy, hilly country; feels his way across a river when the bed is sandy and dangerous, with the greatest caution; hesitates to proceed if he discovers a quicksand; and can extricate himself generally (if a little brushwood be given) under circumstances where a gun (with a team of bullocks or horses) would probably be lost.

During cool weather, or at night-time, his pace is $3\frac{1}{2}$ miles an hour, which can be maintained during a march of 12 or 14 miles; but when the weather is hot, the pace considerably diminishes.

His daily food consists of—

14 to 16 ℔s. of coarse flour;
80 ℔s. of green food.*

Two elephants—one in the shafts, the other as leader—are required for the draught of an 18-pr. gun, or 8-inch howitzer. The following table gives necessary details of these two pieces of ordnance:—

8-pr. Gun.

Details.	Cwt.	Qr.	℔s.	Details.	Cwt.	Qr.	℔s.
Iron gun, ...	42	..	..	Iron gomer, ...	21	..	..
Carriage, ...	45	3	10	Carriage, ...	29	1	6
Limber, ...	15	3	13	Limber,..	15	3	13
Total, ..	..	..	..	Total, ..	66	..	19
Ammunition wagon, ..	21	..	8	Ammunition wagon, ..	21	2	6
Limber, ...	12	3	15	Limber,.. ..	10	3	15
Total, ..	33	3	23	Total, ..	32	2	3

* As sugar-cane, green corn, leaves, branches of the sacred fig tree and of the pipul. Dry fodder is not here mentioned.

Organization of heavy field batteries drawn by Elephants and Bullocks in India.

	Ordnance.			*Carriages.*					*European establ.*		*Native establishment*										*Artificers.*							*Cattle.*		
Number of rounds.	18-pr. siege gun, with dispart sight and tangent scale.	8″ howitz., N.P., with trunnions of the enlarged diameter.	8″ mor. with N. P. beds of 8 cwt.	18-pr. gun with limber and siege handspikes in lieu of O. P.	8″ howitz. with limber, 4 handspikes and elevating screw.	Wagons, ammunition, N. P.	Carts, artificers.	Carts, platform, N. P. Capt. Machell, with regulating field wheels for 8″ mortars.	Quartermaster Sergeant.	Cattle Sergeant.	Jemadar Mahâwat.	Mahâwat.	Coolies.	Jemadar drivers.	Sirdar drivers.	Drivers.	Syces.	Grasscutters.	Bhisties.	Sweepers.	Mistrie smith.	Filemen.	Firemen.	Hammermen.	Mistrie carpentor.	Carpenters.	Múchis.	Elephants.	Horses.	Bullocks.
208 rounds for each 18-pr. 116 do. howitz. 100 do. mortar.	2	1	2	2	2	20	3	2	1	1	1	9	9	1	5	127	5	5	7	1	1	2	2	2	1	2	2	9	5	254
									And a complete company of garrison artillery.																					

Elephants—

3 to each 18-pr. gun and 8″ howitz.

Horses—

1 Sergeant-Major.
1 Quartermaster Sergeant.
1 Cattle Sergeant.
2 Buglers.

Bullocks—

2 18-prs, 20 each,	.. ..	40
1 8″ howitzer,	.. .. ..	16
Carried over,	..	56
Brought forward,	..	56
1 spare hy. carriage,	.. ..	12
25 carriages, 6 each,	.. ..	150
		218
Spare $\frac{1}{6}$,	.. ..	36
		254

The elephant draft-harness consists of—

A large pad, which completely covers the animal from the withers, coming well on the quarters down on both sides, low enough to prevent the skin from being chafed by the shaft or draft chains.

A small pad, on the top of the large pad, to protect the back.

A pad, well stuffed with straw, on which the saddle is placed.

A saddle, whereby the girths can be attached.

A breast-piece and crupper, to prevent the saddle from shifting forwards or backwards.

The back-bands for upholding the shafts.

The breechings, hooking on to the shaft, to back against when going down a slope.

The stirrups for the driver's feet.

It will be noticed that the elephant pulls from the girth, to which, by a hook, the draught and shaft-chains are attached. *See Plate* I.

The weight of—

	Cwt.	Qrs.	Lbs.
The pair of shafts, ...	2	1	8
The shaft-elephant harness, ...	4	3	4
„ leader „	4	0	26
Total, ..	11	1	10

The skin of an elephant is very thick, yet extremely sensitive, and easily worked into sores.

For these reasons, elephants are never branded.*

From " Thirteen years with the Wild Beasts of India," by Sanderson.

The height to which elephants attain is greatly exaggerated; out of hundreds of tame and newly-caught elephants in Southern India, in Bengal, in other parts of India, and in Burma, only one reached a height of 9 $\frac{10}{12}$ feet at the shoulder. This elephant belonged to the Madras Commissariat Stud at Honsur.

There is little doubt that there is not an elephant measuring 10 feet in height in India.

An elephant's height is almost exactly twice the girth of his foot.

The African elephant is, according to Sir Samuel Baker, one foot taller than the Asiatic. *See Plate* II.

It is probable that the elephant lives—

in a wild state to an age of 150 years.
„ tame „ „ 80 to 120 years.

The proper management of the elephants attached to the Military and other departments in India is a subject of much importance.

All elephant-attendants are guided in their conduct by two great principles:

* See table, page
264

(1). To spare themselves work.

(2). And to make as much as they can out of their elephants' rations.

They should hobble the animals easily, and turn them out to graze and stretch their limbs till wanted. When there are fields near, one attendant can accompany the elephant to prevent its doing damage.

If the elephant has to bring in its own fodder, it should do so in the cool hours of the morning and evening.

All ailments to which elephants are subject, are directly, or indirectly, caused by insufficient feeding. Under-fed they become weak and unable to stand exposure; cannot perform their work; and are exposed to sun-stroke and sore-back.

In a wild state, the elephant goes to no excess in any of its habits; and there is no reason, save bad feeding, why the rate of mortality should be so high as it unhappily is among the Government elephants in India. The actual work they have to perform is seldom arduous enough to affect the health.

The amount of fodder required is much greater than is usually supposed. The following table shows the daily Government allowance:—

	Bengal.	Madras.
	lbs.	lbs.
Green fodder, grasses, sugar-cane, branches, ...	400	250
Or in lieu of the above, dry fodder stalks of cut green, ..	240	125

But, by numerous experiments, it has been found that a full-grown elephant will consume in eighteen hours between 600 and 700 lbs. of green fodder, exclusive of that thrown aside. Before full-sized elephants, the minimum allowance per diem should be 800 lbs. of green fodder; the fodder must be good, or it will be insufficient.

As much as an elephant can bring in on his back may be considered as his proper daily supply.

In the Bengal Commissariat Department it has been proved that an elephant will eat daily 750 lbs. of sugar-cane, which is a more nourishing food than 800 lbs. of ordinary green fodder.

The following table shows the cost of keeping a female elephant of full size in the Commissariat Departments of Bengal and Madras:—

	Bengal.		Madras.	
	RS.	A.	RS.	A.
Elephant-driver, ...	6	0	9	0
Grass-cutter, ...	5	0	6	0
Uncooked rice, ...	*8	7	†25	0
Allowance for medicines, ...	0	13	2	0
Fodder allowance, ...	‡3	12	6	0
Total per mensem, ..	24	0	48	0

* 18 lbs. of rice, at 64 lbs. per rupee.
† 25 lbs. of rice, at 30 lbs. per rupee.
‡ At 2 annas per diem.

The chief fodder of tame elephants should consist of various kinds of grasses, which in India, grow to considerable length and thickness. But when these cannot be procured, they are restricted to leaves and branches of trees, which do not form a natural diet. Wild elephants eat sparingly of this fodder.

When well fed, there is no animal less liable to sickness.

Elephant-drivers usually tell the age of an elephant tolerably correctly—

A young animal, of full size, or a very old one, cannot be mistaken ; but it requires much experience to estimate those of middle age.

The old elephant is usually in poor condition ; the skin looks shining and shrivelled ; the head is lean and rugged ; the temples and eyes are sunken ; the fore-legs, instead of bulging out above the knee with muscle, are almost of the same girth throughout.

He brings the foot to the ground after the manner of a plantigrade animal touching with the heels first.

But, in debilitated or middle-aged animals, the above symptoms may be present in greater or less degree.

The elephant's ear will probably settle the question. In very young elephants, up to six or seven years, the top of the ear is not turned over as in man. With advancing years, it laps over, and its lower edge is ragged and torn.

The elephant is full-grown, but not mature, at 25 years of age; and full of vigour till 35 years.

An elephant can only walk, or shuffle, at a rate of 15 miles per hour for a short distance; can neither trot, canter, nor gallop ; does not move with the legs on the same side together, but nearly so ; can neither jump, raise all four feet off the ground, nor make the smallest spring, in height or horizontal distance.

A trench 7 feet wide is impassable to an elephant, although the stride of a large one is 6½ feet.

The elephant's whole character is pervaded by extreme timidity; and to this must be ascribed much of the charging when a herd is suddenly encountered.

Real vice is a thing almost unknown. Natives attach less importance than Europeans to the temper of elephants; all can be managed by some means; and the possession of an unruly animal, if of good figure, is regarded as desirable rather than otherwise.

If flight at any time be necessary, it should be down the steepest place at hand, as elephants fear to trust themselves on a rapid descent at a great pace. Up-hill, on the level, or on broken ground, a man would at once be overtaken.

When a shot is fired at a herd, the whole mass together, shrinking at each shot, till the smoke and smell alarm them.

Doubtless, they believe the noise to be thunder close at hand.

When elephants are close at hand, in indecision, no one should shout to turn them. A charge, by one or more, is almost sure to be made.

When a herd makes off, it goes at a great pace for a short while, afterwards it settles into a fast walk, which is kept up for 10 or 15 miles.

A female with a young calf is more likely to attack a man than $\frac{9}{10}$ths of the male elephants.

Sir Samuel Baker considers the elephant savage, wary and revengeful; Sir Emerson Tennent, the reverse.

Though the elephant has little in his nature that can be called savage or revengeful, he is certainly neither imbecile nor incapable.

If an elephant discover the approach of men at a distance, he almost invariably moves off; but should a man suddenly appear within a few yards, he will be more likely than any other animal to charge.

Though excellent swimmers they are occasionally drowned.

Thus in crossing the Kurnafulie River, 240 feet wide, 30 feet deep, a wild tusker, secured to two tame female elephants, sank (probably through cramp) dragging the two females after him. All three were drowned: the loss was—

	£
The tusker, ...	600
Two females, ...	600
Total loss, ..	£ 1,200

It is rare for the remains of an elephant to be found in the jungles. In Ceylon it is believed that elephants about to die resort to a valley in Saffragáni, among the mountains to the east of Adam's peak.

Elephants, tame or wild, suffer from an epidemic resembling murrain. It attacked the elephants in the Government Stud at Dacca, in Bengal, in 1848, and carried off nearly 50 per cent. out of a total of three hundred. It lasted for ten years—

The symptoms were breakings out and gatherings on the throat and legs; spots on the tongue, and running from the eyes. With the cessation of the flow from the eyes the animals usually died on the second day after the attack.

In 1862 an epidemic of this sort carried off large numbers of wild elephants in the Chittagong forests; later the herds in Maisur suffered.

The most common ailment amongst elephants is Gaarba'hd, which is of two kinds :—

In the dropsical form, the neck, chest, abdomen and legs swell with accumulations of water beneath the skin.

In the wasting Gaarba'hd, the animal falls gradually away to mere skin and bone.

The disease, in both its forms, is exceedingly fatal ; it occurs chiefly in newly-caught animals, induced by the radical change introduced in food and habits.

Freedom from unnecessary restraint, liberty to graze at will, protection from all debilitating causes (such as exposure to sun, or inclement weather) are the best preventives and restoratives. Medicine is of little avail ; and if the disease becomes serious, there is every probability of a fatal termination.

Sore-backs, from the chafing of gear, are very tedious to cure. The elephant-drivers usually allow the wounds to heal on the surface, while mischief is going on within. The best treatment consists of—

A free use of the knife.

Care in cleansing the wound.

The application of turpentine impregnated with camphor.

The filling of deep burrowing holes in sore backs with tow, steeped in camphorated turpentine.

The keeping of a cloth, steeped in Margosa oil, over the wound.

When elephants require a purgative, they eat a black soil impregnated with natron. Purging ensues in twelve to twenty-four hours.

An elephant becomes foot-sore from working in gravelly or stony soil ; does not limp, but goes more slowly and tenderly. Rest is the best treatment.

It is probable that a female elephant may have two calves at a birth* ; many wild female elephants are accompanied by two or even three calves of different ages.

Elephants breed once in 2½ years ; two calves are usually sucking at the same time.

At the time of birth a calf stands 3 feet at the shoulder ; its trunk is 10 inches long ; its weight 200 lbs. It lives entirely upon milk till six months old, when it eats a little tender grass ; it drinks with its mouth. The female elephant evinces no peculiar attachment to her offspring.

The elephant rarely breeds in confinement. This is due to the segregation of the sexes, to insufficient food, and to hard work. In Burma and Siam, they are bred in a semi-wild state.

In India from an economic view, it would not answer to breed elephants as before they were of useful age (15 years), they would have cost

* See page 247.

more than would suffice to capture a number of mature wild ones, ready for work.

When an alarm occurs in a herd, the calves immediately vanish under their mothers, and are seldom again seen. The mothers help their offspring up steep places with a push behind, and manage to get them cleverly over every difficulty.

Female elephants usually give birth to their first calf at 16 years, sometimes at 13 or 14.

The period of gestation is said to be—

22 months in the case of a male calf.
18 months „ female „

The female elephant may conceive eight or ten months after calving.

Male elephants of mature age are subject to periodical paroxysms, supposed to be of a sexual nature. In this state they are said to be "mast," or mad.

Fits of *mast* vary in duration in different animals; in some they last for a few weeks, in others for four or five months.

In this state they are sometimes violent and intractable; sometimes drowsy and lethargic. The approach of the *mast* period is indicated by the flow of an oily matter from the small hole in the temple, on each side of the head, found in all elephants, male or female. The temples also swell.

On the first indications, the elephant should be strongly secured; if he becomes dangerous, food is thrown to him, and water supplied in a trough pushed within his reach.

Fatal accidents are of common occurrence; they attack man, or their own species.

Some male elephants have these fits at long intervals; some have them regularly. They occur in wild individuals, in the cold weather, from November to February. It is believed that the wild (unlike the tame) elephant shows no violence at this period. It rarely takes place in animals much below par, or under 30 years of age, though tuskers breed from the age of twenty years.

The flow of *mast* seldom occurs in the wild female elephant; and never in the tame.

The elephant's chief qualities are—

Obedience.
Gentleness.
Patience.

He is excelled in these by no domestic animal; evinces rarely any irritation under circumstances of the greatest discomfort (such as exposure to the sun, painful surgical operations); refuses rarely to do that which he is required if he understands the nature of the demand, unless it be something of which he is afraid; is very timid, both in his wild and domesticated state, and is easily excited by anything strange.

The elephant is essentially a native's animal.* The trade of selling and buying, his capturing, training and keeping are in natives' hands. Elephants are divided into three classes—

Koomeriah or thorough-bred.
Dwasala or half-bred.
Mírga or third-rate.

Whole breeds may consist of Dwasala, but never of Koomeriahs, or Mírgas alone.

The parts of a Koomeriah are—

Barrel deep and of great girth ; legs short (especially the hind ones) and colossal ; the front pair convex on the front side, from the development of muscle; back straight and flat, but sloping from shoulder to tail, as a standing elephant must be high in front ; head and chest massive, neck thick and short ; trunk broad at the base and heavy throughout : hump between the eyes prominent ; cheeks full, eyes full, bright and kindly ; hind-quarters square and plump ; the skin rumpled, inclining to folds at the root of the tail, and soft ; tail long and well feathered.

If the face, base of trunk and ears be blotched with cream-coloured markings, the animal's value is enhanced.

The Dwasala class comprises all those below this standard, not descending so low as the third class.

The parts of a Mírga are—

Legginess, lankiness and weediness ; arched sharp-ridged back, difficult to load and liable to galling ; trunk thin, flabby and pendulous ; neck long and lean ; falling off behind ; hide thin ; head small ; eye, piggish and restless ; and altogether unthrifty, which no feeding improves.

He is generally fast.

See Plates I and II.

The tusks of the Asiatic elephants are smaller than those of the African.

Details of the largest known tusk of an Indian elephant are given below—

	Tusk			
	Right		Left	
	Feet.	Inch.	Feet.	Inch.
Total length, outside curve, ...	8	0	3	3
Length of part outside socket, or nasal bones, outside curve, ...	5	9	1	2
Length of part inside socket, outside curve, ..	2	3	2	1
Greatest circumference, ...	1	4·9	1	3
Weight, ...	lbs. 90		lbs. 49	

* Hence the value of information like that given by Abú-l-Fazl. See page 248.

The tusks are fairly embedded in sockets of bone, running up to the fore-head, and ending at a line drawn from eye to eye; are (save in the case of very aged elephants) only solid for a portion of their length, the hollow being filled with a fine bloody pulp; are solid in young animals, for a portion only of their length outside the gum; appear at birth and are supposed to be permanent. With age the pulp cavity decreases in depth, till in old animals it becomes almost obliterated. As a rule, tusks show barely one-half of their total length outside the jaw of a living animal. Of a large elephant—

The sockets or nasal bone in length are, ..	1 ft. 6 in. to 1 ft. 9 in.
The portion hidden by the gum is, ..	1 ft. 4½ in.

An estimate of the calibre of a wild tusker may be gathered by the impression of his tusk in the soil. One that will admit five fingers in the groove is well worth following.

The tusks may easily be removed by hand if the beast be left dead for ten days. If they be cut out at once, the flesh along the nasal bones up to the eye must be removed, and the tusk-cases split with a hatchet; they are usually blemished in the process.

Tusks though not used to assist the elephant in procuring food, are not useless appendages, but amongst the most formidable of any weapons with which nature has furnished her creatures, and none are used with greater address. Small trees are overturned by pushing with the curled trunk, or feet, if necessary. To get at the core of a palm-tree; or to break up a plantain, the pressure of the foot alone is used.

In a herd, the tuskers maintain the height of discipline; every individual gives way to them; and, in serious fights amongst themselves, one is frequently killed outright.

Superiority appears to attach to the different tuskers in proportion to the size of their tusks; no tusker thinks of serious rivalry with one of heavier calibre than himself.

In the "khedās" of Mysore, two tame tuskers (taller and with longer tusks than any wild ones captured) were sufficient to awe the most obstreperous wild male, whilst the men secured him.

The tame elephant's tusks were cut blunt; but steel glaives were ready to slip on; and they could, with these, have killed any elephant in a short time.

In India "Mukhnas," or male elephants born without tusks, are rare.

Mukhnas can hardly be distinguished from females; but if full grown, their superior size shows their sex. Their tushes are generally a little longer and thicker than those of female elephants. They are stouter and more vigorous than tuskers; are generally ill-treated by the tuskers of the herd upon whom they are powerless to retaliate; and hence are sometimes timid.

The absence of tusks is an accidental circumstance, as the want of beard or whiskers in a man. Mukhnas breed in the herd, and the peculiarity is not transmitted. This is a known fact, demonstrated by the occasional occurrence of tuskers (doubtless from tuskless sires) in Ceylon herds.

In Ceylon a male elephant with tusks is rare. Sir S. Baker says that not more than 1 in 300 are provided with them.

In Mysore and Bengal, in 1874-76, out of 140 elephants, (of which 51 were males,) only 5 were mukhnas.

Elephants occasionally lose one tusk (sometimes both) by accidents in the jungle; and some have only one tusk at birth. The latter are known as Gunesh (the Hindu God of Wisdom); and, are reverenced, if the tusk existing be the right hand one.

The Indian female elephant is always born with tushes 4 inches in length outside of the gum; these, while present, are used for stripping bark of trees; but they are generally broken off early in life, and are never renewed.

It may be mentioned that elephants' bones are solid, without marrow.

The trunk, a delicate and sensitive organ, never used for rough work, is used to procure food and water, and to convey them to the mouth. In a dangerous situation, it is curled up; if upraised in attack, it would obstruct the animal's sight.

In carrying a light log, they hold it in the mouth as a dog does a stick, balancing it with the trunk.

Tuskers use their tusk for this and similar purposes, and are consequently more valuable than females.

An elephant pushes with the *base* of the trunk, one foot below the eye.

The trunk is rarely used for striking. Newly-caught elephants curl their trunks and rush at the intruder.

In drinking, only fifteen inches of the end of the trunk are filled with water at a time.

The trunk of a wild elephant is occasionally cut by the sharp edges of split bamboos while feeding.

When an accident happens, which prevents him from using his trunk for procuring water, he drinks by wading into deep water and immersing his mouth.

An elephant is taught to trumpet by the extremity of his trunk being tightly grasped between the hands, when he is obliged to breathe through the mouth, in doing which he makes a loud sonorous sound.*

The elephants at the elephant depôt (*píl-khâna*), at Dacca, are better trained than those in Southern India.

The *píl-khána* covers a quarter of a mile; it consists of an intrenched quadrangular ground in which the elephant's pickets are arranged in rows. At each picket is a masonry flooring with post at the head and foot to which the animals are secured. In a shed many hundred feet long running along one side, the elephants are kept during the heat of the day.

There are—

> A hospital for sick elephants.
> Houses for gear.
> A room for the Native Doctor.
> A shelter for howdahs.

The annual captures—

> Between 1836–1839, were 69.
> „ 1869–1876 „ 59.

The hunting season is from December to April, and the training season, from May to November.

In India the wild elephant enjoys perfect immunity—

> Throughout the Western Ghats,
> In the jungles at the foot of the Himalayas,
> In Burma,
> In Siam.

The number annually caught is very small. In Southern India ele-

* Mr. Sanderson seems to doubt whether there is such an animal as a white elephant.

In the Sikandar-náma, by the Persian poet Shaikh Nizámi, A. D. 1181 (translated by Wilberforce Clarke), Discourse 58, couplet 21, we have:—

شہ The King (Sikandar), robust of body, possessed of a thousand hopes.
کمر بست بر پشت Bound his loins on the back of a *white* elephant.

See also page 245 of this Note.

The tenderness of the elephant's foot was well known to the Persians. In the Sikandar-náma, Discourse 45, couplet 60, we have:—

زبر خاش او پیش گیرم رحیل Instead of contest with him, I will choose departure;
نیندازم این دبهٔ در پای پیل At the elephant's foot, I cast not this "dabba."

The "dabba" was a leathern bag filled with gravel which they used to strike upon the elephant's feet (the most tender part of his body) to make him furious.

phants have become so numerous of late years, that the rifle will have to be again called into requisition to protect the peasants from their depredations.

In Ceylon and in Africa, the elephant has greatly decreased in numbers.*

The full strength of the elephant-establishment in the Lower Commissariat Circle of Bengal is 1,000: of these, the casualties in the year 1874-75 were as follows:—

Falling in traps,	1
Larza,	5
Stomach-diseases,	6
Calving,	8
Zahr-bád,	26
Fever,	4
Injuries,	4
Brain congestion,	1
Apoplexy,	11
Dysentery,	3
Colic,	3
Vomiting,	1
Inflammation of lungs or bowels,	5
Escaped,	6
Internal diseases,	15
Debility,	13
Drowned,	5
Cold,	1
Destroyed,	1
Total Casualties,	114 or 11·4 per cent.

The wild elephant's attack is one of the noblest sights of the chase—

The cocked ears and forehead present an immense frontage; the head is held high with the trunk curled between the tusks, ready to be uncoiled at the moment of attack; the massive fore-legs come down with the force and regularity of ponderous machinery.

The trunk being curled and unable to emit any sound, the attack, after the premonitory shriek, is made in silence.

In herds, the rear-guard should be examined for tuskers, as they seldom go in front. The most ordinary precaution will enable a sportsman to move to within a few yards of them, if in cover, so long as they keep the wind. It is seldom that they cannot be approached to within 10 yards.

A tusker rarely undertakes to cover the retreat of a herd, but takes a line of his own when danger threatens.

* It is much to be desired that, as in India, means should be taken to preserve this valuable in Ceylon and Africa.

The alarm of man's presence is usually communicated by the elephant that discovers it by a peculiar short shriek, which can be distinguished from all other sounds.

If hard pressed, females with calves will turn upon their pursuers. The stampede of a herd is overwhelming; amidst the crushing of bamboos and tearing down of creepers from high trees, it is for a moment impossible to say which way they are making. The best thing is to stand still against a tree, or bamboo clump. Elephants are poor-sighted, and so intent on making off when startled, that one may be brushed by them without being discovered.

In the case of a dead elephant, the carcase swells to an enormous size; the legs on the uppermost side become stiff and project horizontally. Many hundreds of vultures collect on trees or fight for a seat on the carcase, awaiting the time when they can make a commencement.

At the end of six days, when the carcase bursts and collapses with rottenness, it is crawling with millions of maggots and white-washed with the droppings of the filthy birds.

The spot resounds with the buzzing of flies, and the stench is so great as to be perceivable half a mile to leeward.

In a few hours, the vultures reduce the carcase to a pile of bones and a heap of indigested grass.

When the birds have left, the whole neighbourhood is pervaded with the pungent odour of guano; and the site of their feast is trampled into a puddle by their feet.

Wild hogs not unfrequently feed upon the carcase; and it is not unlikely (as stated by the natives) that tigers also do.

The foot of the elephant makes an excellent foot-stool; the round fore-feet are better than the oval hind.

The foot should be cut off a few inches below the knees; be freed of the bones and flesh; be well rubbed inside and outside with arsenical soap and folded away for packing; be softened in hot water after the sportsman's return to head-quarters, and rubbed with arsenical soap; and be placed, filled with sand, in the sun, all loss by shrinking being prevented by frequent ramming. When thoroughly hard and dry, the sand must be removed, the feet stuffed with coir; the nails scraped till white, and the skin covered with lamp-black.

Both skin and nails should then be varnished, and the top of the foot covered with panther's skin secured round the edge with large-headed brass or silver nails.

Small feet—with a tray inside, and a mahogany or silver lid surmounted by a small silver elephant to lift it off by—make good cheroot-boxes. They will serve also as inkstands, ladies' boxes, &c.

From Emerson Tennent's "Ceylon," Vol. 2, Part 8.

The economy of maintaining a stud of elephants for the purposes to which they are assigned in Ceylon is questionable. In wild parts of the country, where rivers have to be forded and forests are only traversed by jungle-paths, their labour is of value. But, in more highly civilized districts, and wherever macadamized roads admit of the employment of horses and oxen, the services of elephants might gradually be dispensed with.

The love of the elephant for coolness and shade renders him impatient of work in the sun, and every moment of leisure he can snatch is employed in covering his back with dust, or fanning himself to diminish the annoyance of insects and heat. From the tenderness of his skin and its liability to sores, the labour in which he can most advantageously be employed is that of draught; but the reluctance of horses to meet or pass elephants renders it difficult to work the latter with safety on frequented roads. Besides, where the full load of which an elephant is capable of drawing, to be placed upon a wagon, the injury to roads and bridges would be great; and, by limiting the weight to 1½ tons, it is doubtful whether an elephant performs so much more work than a horse as to compensate for the greater cost of its feeding and attendance.

From ulcerated abrasions of the skin and illness of many kinds, the elephant is so often invalided that the actual cost of his labour, when at work, is greatly enhanced.

The expenses of an elephant (excluding the salaries of higher officers and permanent charges, but including the wages of three attendants and cost of his food and medicine), varies from 3 to 4½ shillings per diem, according to his size and class.

If he be employed (as is usual) four days out of seven, the charge per diem would be 6½ shillings. The cost of a dray horse could not exceed 2½ shillings, and two would do more work than an elephant under the present system.

As a beast of burden, he is unsatisfactory, for it is difficult to pack any weight without causing abrasions that afterwards ulcerate. His skin is easily chafed, in wet weather, by harness ; his feet during long draughts, or too much moisture, are liable to sores, which render him non-effective for months; his eyes are liable to frequent inflammation, in the relieving of which native elephant doctors are happily skilled; whether wild or tame, he suffers severely in times of murrain, and is, on being first put to work, liable to severe and often fatal swellings of the jaw and abdomen.

Between 1831 and 1856 240 elephants died. The following table gives details of 138 of these :—

Duration of Capture in years.		No.	*Sex.*	
From	To		Male.	Female.
1	...	72	29	43
1	2	14	5	9
2	3	8	5	3
3	4	8	3	5
4	5	3	2	1
5	6	2	2	...
6	7	3	1	2
7	8	5	2	3
8	9	5	5	...
9	10	2	2	...
10	11	2	2	...
11	12	3	1	2
12	13	3	...	3
13	14	3	1	2
14	15	1	1	...
15	16	1	...	1
16	17	...	...	...
17	18	2	1	1
18	19	1	1	1
19	20			
	Total, ...	138	62	76

The elephant's obedience to his keeper is the result of affection and of fear.

If the attendant's eye be withdrawn, the moment he has done the thing immediately in hand, he will stroll away to browse, or to fan himself. He is guided by what is called—

Lendee in Ceylon.
Gaj-bāg ; āñkus ; āñkūs in Bengal.
Cuspis in Latin.

The most vicious and troublesome elephants to tame and the most worthless when tamed, are those distinguished by a thin trunk and flabby pendulous ears.

The period of tuition does not depend upon the bulk; some of the smallest give the greatest trouble; the males are generally more unmanageable than the females; those most obstinate and violent at first are the soonest subdued; those sullen and morose are rarely to be trusted in after-life.

The elephant of Africa was tamed, but not to the same degree as the animals of India, by the Carthaginians.*

The elephant particularly dislikes the sound of dah! dah!

The perfection of form consists in—

Softness of the skin; red colour of the mouth and tongue; forehead expanded and hollow; ears large and rectangular; trunk broad at the root and blotched with pink in front; eyes bright and kindly; cheeks large; neck full; back level; chest square; fore-legs short convex in front; hind-quarter plump; and five nails on each foot, all smooth, polished and round.

Such an elephant cannot be discovered among thousands.

The colour of the animal's skin in a state of nature is of a lighter brown than when in captivity. This is due to care in bathing and in rubbing their skins with a soft stone, a lump of burnt clay, or the coarse husk of a cocoanut.

The export of elephants from Ceylon to India has been going on since the first Punic war.

There are few places where man can go that an elephant cannot follow,—provided there be space to admit his bulk, and solidity to withstand his weight.

It is to the structure of the knee-joint that the elephant is indebted for his singular facility in ascending and descending steep acclivities, climbing rocks, traversing precipitous ledges where even a mule dare not venture.

The spoor of an elephant was in 1840, found on Adam's peak, 7,420 feet in height, on a pinnacle which pilgrims with difficulty climb.

The range of vision is circumscribed; he relies on his powers of hearing and smelling, which are very acute.

* At the present time, it is believed that there is not a single tame African elephant in the world. The *Indian Daily News* of the 7th May 1879 says:—The British Indian Company's Steamer "Chinsura" is being fitted for the reception of four elephants, which are to be shipped from Bombay to Zanzibar for the use of the expedition to Central Africa started by the King of the Belgians.

The sounds which he makes are of three kinds—

The first, blowing through the trunk, indicative of pleasure.
The second, produced by the mouth, expressive of want.
The third, proceeding from the throat, a terrific roar of anger.

In captivity, when standing at rest, some elephants move the head monotonously in a circle, or from right to left and swing their feet backwards and forwards; others flap their ears, swing themselves from side to side, and rise and sink by alternately bending and straightening the fore-knee. In short, their temperament is fidgetty.

During thunderstorms, wild elephants hasten from the forests to open ground, where they remain till the lightning ceases.

Even when charging, an elephant will hesitate crossing an intervening hedge, but will seek for an opening. Fields enclosed with fences of sticks —1 inch in diameter and 5 to 6 feet in height—are safe from his inroad.

In the dry beds of rivers, elephants scoop out the sand to the depth of 4 or 5 feet to obtain water; one side of the pool forms a shelving approach so that they can reach the water easily.

The rogue, or solitary, elephant is supposed to be a wild elephant who has by accident become separated from his own herd, or a tame one who has escaped.

Although two rogues may be in the same vicinity, they do not associate; the rogue is supposed to be always of the male sex.

From their closer contact with man, these outcasts become disabused of many of the terrors which render the ordinary elephant timid.

From the revised Memorandum of Instructions regarding care and keep of Elephants, by the Commissary General, Bengal.

Elephants (average weight, full size, 5,740 lbs.) should be laden and unladen expeditiously; should not be kept kneeling or standing; should not be overloaded, or employed for purposes other than those for which supplied.

After a march, the animal should stand for a while with the pad on to cool; when it is removed, hot water and salt should be rubbed into the back; after travelling over rough and stony ground, *chobe* should be applied to the feet. Six hours' work in the cool of the morning is a good day's work. Elephants should be bathed twice a day when halting, and be well rubbed down while in the water; should not be bathed when infested with worms (Nāgā); should be watered twice a day, from wells or running streams, when cool; should be sent for fodder one hour after arrival in camp; should be watered on bringing in their fodder, picketed under trees (or with jhúls in the sun) with their day's fodder before them, paraded at 6 or 7 P.M., to eat their flour or rice cake, after the afternoon bath, and then picketed (if possible on open ground, with their *night's* allowance of fodder before them ; should, in the cold season always wear jhúls when standing ; should not be picketed by the fore-foot unless necessary ; and should be daily examined as to the feet, for injury from treading on bones, thorns, or burnt grass, &c.

Tree fodder is heating and should be given in the rains only ; plantain trees should be cut in pieces 1 foot in length.

Fodder, weighed, should be always before the animals. The daily allowance is 410 lbs. green, or 246 lbs. dry.

Flour should be inspected, weighed, cooked and given at once to the animals to avoid pilfering ; eight sírs of rice flour should weigh 10 sírs 4 chhatáks when cooked.

Rice should be given, in small quantities, tied up in straw, by the hand.

Neither flour, nor rice, should be given when elephants eat earth to expel worms.*

Fodder and coarse flour are to be given by the gumashta (clerk) ; masálih (spices or drugs) by the Executive Commissariat Officer.

Elephants should be taken off duty if they show any signs of illness ; and, when galled, made over to the nearest Commissariat Officer with a report as to the cause of the injury.

Elephant-drivers failing to report the slightest signs of galls should be severely punished. The backs are to be daily examined and—if the back be swollen or bear the appearance of abrasion—camels and carts are to be employed in the following proportion :—

3 Camels = 3 or 4 Bullock carts = 1 Elephant.

Pads should be kept well filled, and inspected daily ; and the gaddi filled with coarse sholá (pith) instead of grass, as it is cooler, lighter, and less absorbent. All over Lower Bengal, sholá is obtainable.

Elephant-drivers should be reported for ill-treating or neglecting their animals, for making a noise to prevent their sleeping, for allowing them to leave their pickets under coolies, and for giving drugs (masálih). They are not allowed to sit upon the baggage (as they then use a long spear), to cut fodder from trees near villages, sacred places, or fields, nor to use the gaj-bāg, save where in charge of "mast" animals.

In the case of Civil Departments, elephants—

(*a*) are to be applied for only when no other suitable carriage is available ;
(*b*) are not to be taken 50 miles from their stations ;
(*c*) are to be made good, at the cost of the Civil Department by which they were employed, when returned injured, or out of condition ;
(*d*) are to be lent only when of good temper.

Each elephant should be provided with :—

	Weight.	
1 Bandhan ...	... 38 sírs.	fetters.
1 Berī (anklets) ...	... 22 „	
1 Phāns (noose) ...	... 14 „	

All "mast" elephants, when going to feed, to water, or on duty, should wear fetters. Gear and fetters should be inspected at muster and weekly parades.†

* See pages 253, 258, 284 and 288.

† The gear appears to be the same as that given on page 251. The sir is equal to 2 lbs.

The following table gives details of the fodder* which can be given to elephants:—

Name of Fodder.		When procurable.	Qualities.
Hindústani.	Botanical.		
Bājrā, green, ..	*Holcus spicatus* ..	Autumn ..	Nutritious, wholesome, and cooling.
„ dry, ..	„ ..	Cold weather ..	„ „ but heating.
Bambū, ..	*Bambusa* ..	Always ..	„ „ and cooling. Elephants should be allowed to graze well in bambū jungles.
Bargad, ..	*Ficus Indica* ..	„ ..	Nutritious and wholesome. To be given with grass food, but not when throwing out new leaves.
Churrī, green, ..	..	In rains ..	Nutritious, wholesome and cooling.
„ dry, ..	..	Always ..	„ „ „
Dālī (branches), ..	..	„ ..	„ to be given with grass and plantain.
Dāl, ...	*Vetch* ..	„ ..	„ and wholesome, but rather heating.
Dhān, with stalks, ..	*Butica brondosa* ..	„ ..	„ wholesome, and cooling.
„ straw, ..	„ ..	„ ..	„ „ „ good when fresh.
Dūmar, ...	..	In rains and cold weather.	Rather heating; should be given sparingly, as it creates worms.
Dul, ...	*Panicum stagnitum* ..	In rains ..	Cooling. Small quantities of tree fodder should be given with this.
Akrā, ...	..	Always ..	Nutritious and cooling.
Farad or Madār, ..	..	.. ..	Cooling, scarce. Given occasionally.
Gūlar, ...	*Ficus ræmosa* or *Glomorata*	In rains ..	Heating, but nutritious.
Goonja, ...	..	„ ..	Nutritious and cooling.
Grass, green, ..	..	„ ..	Wholesome „

* The Indian names, as far as possible, have been corrected as to spelling.

Name of Fodder.		When procurable.	Qualities.
Hindústani.	Botanical.		
Grass, dry, ..	..	Always ..	Wholesome and cooling.
„ of kinds, ..	*Graminacca buza stipa* ..	„ ..	„ „
Kathal (Jack), ..	*Artocarpus nitogrifolia* ..	„ ..	Heating, but wholesome.
Jewul, ...	..	„ ..	Slightly heating but nutritious. Before and after eating earth, elephants eat this with avidity.
Jhil fodder, ..	*Graminacca buza stipa*	„ ..	Nutritious, but heating.
Jawār, green, ..	*Sorghum vulgare* or *Holcus sorghum.*	In rains ..	Wholesome, cooling and nutritious.
„ dry, ..	„ „ „	In cold weather ..	„ and nutritious.
Keorā, ..	..	..	Cooling and nutritious. Elephants appear to enjoy it thoroughly.
Kāns, ...	*Saccharum spontaneum* ..	In rains ..	Cooling and nutritious.
Khaooed, green, ..	*Hordeum hexastichon* ..	„ ..	„ „
„ dry, ..	„ „ ..	In cold weather ..	Cooling, nutritious and wholesome.
Khookhsa, ..	..	Always ..	Not very nutritious, but heating.
Killuck, ..	..	„ ..	Nutritious, medium heating.
Kuggra, ..	*Saccharum spontaneum* ..	„ ..	„ „ „
Kurbi, green, ..	*Holcus sorghum and Zea Mays*	In rains ..	Cooling, wholesome, and nutritious.
„ dry, ..	„ „ „	In cold weather ..	„ „ „
Kasilā, ..	*Poa cynasaroides* ..	In rains ..	Wholesome and nutritious.

Lakur, ..	..	Always ..	Nutritious, medium heating. Good, except when throwing out new leaves.
Lote, ..	..	,, ..	Nutritious, medium heating.
Makkī, ..	*Zea Mays* ..	In rains ..	Wholesome and nutritious, but rather heating.
Megla, ..	..	Always ..	Nutritious, medium heating.
Muruā, ..	..	In rains ..	,, wholesome, and cooling.
Nerūā, ..	..	Always ..	,, medium heating.
Nuraie, ..	..	,, ..	,, ,, ,, elephants eat earth if given much.
Nal-khakron, ..	..	,, ..	Nutritious, medium cooling; creates worms; not recommended.
Narakul, ..	*Arundo libiates* ..	,, ..	Nutritious, wholesome and cooling; creates worms; not recommended.
Narkat plant, ..	..	,, ..	Not nutritious, creates worms; not recommended.
Narkat, ..	..	,, ..	Nutritious, medium cooling; creates worms; not recommended.
Oree, ..	..	,, ..	Nutritious, medium cooling.
Pākar, ..	*Ficus venosa* ..	,, ..	,, wholesome, but heating.
Pipul, ..	,, *religiosa* ..	,, ..	,, ,, but very heating. To be given with grass or plantain; not good when throwing out new leaves.
Kilā (Plantain), ..	*Musa sapientium* ..	,, ..	Not very nutritious, but very cooling; should be cut in small pieces not more than one foot in length.
Puttala, ..	*Panicum spicatum* ..	,, ..	Not very nutritious; cooling.
Pussar, ..	..	In cold weather ..	Nutritious and cooling.
Saloe, ..	..	,, ..	,, wholesome, and cooling.
Simal, ..	*Bombax moraboricum* ..	Always ..	Fairly nutritious, but rather heating.
Gannā (Sugar-cane),	*Saccharum officinarum* ..	In cold weather ..	Very wholesome & nutritious when young & green; cooling.
Suna, ..	..	Always ..	Nutritious, medium; given when quite young.
Torra, ..	..	,, ..	Nutritious; heating; strengthening during cold weather.

The Indian names, as far as possible, have been corrected as to spelling.

Elephants will receive, when "mast," half rations of coarse flour or rice, the cost of the difference being laid out in green fodder; when eating earth (for worms), none.*

In crossing rivers, an unloaded elephant should act as pioneer; any in a heated state should not be allowed to cross. If he gets into quicksand, give branches and water to loosen the sand.

The tusks should be cut at a distance from the lip equal to that from the eye to the lip. In young animals, this distance is insufficient. If the medullary pulp be reached, it bleeds after the operation, and the tusks split and decay. If the whole tusk split up to the root, cut off where it touches the gum. Tusks that are cut should be protected with brass (not iron) rings.

The general appearance should be as follows:—

A good elephant should have short and stout limbs, the shoulder somewhat higher than the rump; back short and somewhat bowed, or, as it is termed, hog-backed.† When properly fed, such elephants become rapidly round-sided, and retain their condition well. Elephants with long, high-ridged, straight backs are not so strong as those above noted, neither do they keep their condition so well, and in work their flesh soon falls away from the back-bone, leaving it exposed and very liable to rub into sores from the friction of the loads.

The trunk should be long and well stretched; the extremity of the tail large and bushy; the ears large and constantly in motion.

Nails and feet.—Make the animal lie down, and examine the toe-nails most carefully; if splits of any kind be discoverable in the nails, the animal should be rejected. Tap the foot all over the sole with the point of a walking-stick, to discover tender sores.

The lower part of the foot and above the nails should be free from any rough, or scaly, pieces of flesh, which are very troublesome in wet weather, and likely to get into sores. The natives call it "chajoon." These superfluities should be pared off.

Action.—In examining an elephant, make your own mahāwat (elephant-driver) urge him to his fullest speed. Defects of lameness, &c., are far more readily discovered when the animal moves rapidly, activity of stepping is a good sign, and free action from the shoulder with the foot firmly planted, and no heavy rolling of the body; the latter would indicate that the elephant has been made to carry loads heavier than he ought to bear.

Three years is the earliest that an elephant should be purchased after his first seizure.

Elephants up to 45 years are at the very best age for purchase; they will do good work to 80 years of age and upwards.

* See pages 253, 258, 280 and 288.

† See pages 270 and 278. This is at variance with the descriptions there given.

Some would determine the age from the concavity of the palate ; this is no safe test. The palate of the male elephant, as it ages, grows hollower ; but, that of the female does not change much, remaining nearly flat.

A more certain method is to judge by the overturning of the upper lap of the ear. When turned down about one inch, the elephant is supposed to be about 30 years old ; from one inch to two inches, ranging from 30 to 60 ; and above two inches old.

The male is the strongest animal, but owing to his becoming annually "mast" after he has arrived at full growth, the female is generally preferred. The usual season for the male to become "mast" is for three months during the rainy season.

The following points should be noticed—

Cleanliness of the stable.

Nāga* elephants, eating rations† are purged to death, and should not be bathed.

Sores arising from ropes are cured by chiknimitti (potter's earth), leather stomach-protectors under the ropes, which chafe the belly, are recommended ; injection pumps are useful as syringes for washing out sinuses.

Dropsy, zahr-bád. *Symptoms*—Glandular swellings behind the ear, under the throat in the groin, or between either hind or fore-legs ; eyes become dull ; trunk shrivelled; urine very red *Treatment*—Bleed ½lb. behind the ear ; apply a strong blister of common blistering ointment mixed with sulphuric acid (1 drachm to the oz.), well rubbed into parts affected. If the swelling falls downwards, the animal will recover, but the swelling in its downward course must be followed by the blister until it finally disappears. If behind the ear, it generally falls down the jaw, and disappears at the lip. If between the legs, it generally disappears at the knee-joint. If, instead of falling, the disease should spread, it will cause the death of the elephant, on the third day.

Or adopt the following :—

I. Blister the affected part three times, the first day, with Spanish flies (cantharides); and make a mixture as follows :—

3 oz. iodine.
10 „ spirits of turpentine.
5 „ camphor.

Add the iodine to the turpentine until it is dissolved ; and the camphor broken up very fine to the other two. This mixture should be applied (to the parts blistered) with a scrubbing-brush.

II In ordinary zahr-bád, dropsy, caused by too much green food, tap the animal at once ; and keep the tap open.

III Sukha, or dry zahr-bád, the result of neglect, want of cleanliness, over-work and irregular feeding. *Symptoms*—Animal pines away to a skeleton, becomes speckled, assumes a shiny grey colour, and tries to scratch itself on the legs. *Treatment*—The animal is to be washed twice a day in clean water, well dried, and rubbed well with tillee oil (petroleum, when procurable) three times a week. The skin is in a very tender state, and should be protected from the sun, which will crack it ; and from the rain, which will rot the scurf skin, and produce a state of intense rawness.

* The term nāga, I imagine, comes from nag, a snake; nāga will then mean *wormy*.
† See pages 253, 258, 280 and 288.

From Diseases of the Elephant by Major Hawkes.

In this treatise, the supposed remedies for the diseases of elephants are clearly laid down; it is foreign to the purpose of this note to insert it; and extracts would be of little service.

In a different sense, the same remark applies to the Treatise on the Comparative Anatomy of the Indian Elephant; and to Colonel Cooke's Aide-Memoire.

From a practical memoir of the history and treatment of the diseases of the elephant, by Assistant Surgeon W. Gilchrist.

Of a female elephant the dimensions of which were—

	Ft.	In.
Height, ...	7	4
Length from top of forehead to insertion of tail, ..	10	1
Round abdomen, ...	13	8
Length of small intestines, ...	68	0
" large "	38	8

The weight of the parts were—

	Cwt.	Qrs.	Lbs.
Head, including trunk, weighing 16¼lbs., ...	4	0	22
Left fore-leg, ...	2	2	25
Right "	2	2	14
*Left shoulder, ...	0	3	18
*Right "	1	0	7
Left hind-leg, ...	2	2	11
Right "	2	3	0
*Left ribs, ...	1	1	20½
*Right ribs, ...	2	0	26
Loins and part of buttock, ...	3	0	16
Pelvis, ...	3	1	19½
Neck, ...	0	3	13
Breast-bone, ...	0	3	9
Weight of carcase, ..	28	3	10
Heart, ...	0	1	14
Legs and diaphragm, ...	0	3	14
Kidneys, ...	0	0	16
Intestines (small and large bowel), ...	2	1	23
Liver, ...	0	2	20½
Spleen, ...	0	0	4½
Stomach, ...	0	3	12
Weight of carcase and organs, ..	34	1	2
Dung, ...	2	1	9
Water in bowels in cavity of abdomen, ...	2	1	18
Grand Total, ..	39	0	1

* How are these differences reconciled?

The skin varies in thickness from ¾-inch to 1 inch about loins and buttocks.

This weight approximates to that fixed in the Commissariat Department as the average weight of an elephant—

Tons.	Cwt.	Qrs.	Lbs.
2	10	1	22

The testicles are contained within the abdomen, near the kidneys; castration is consequently impossible.*

Bleeding is best performed by partially, longitudinally, incising the arterial trunk on the back of both ears, when the animal is in a lying posture; it may also be effected from a vein in either of the hind-legs, or above the under-part of the sides of the abdomen. The jugular vein is four inches beneath the surface.

	gallon.		lbs.
An ordinary bleeding amounts to	1	of blood =	10
A full „ „	1½	„ =	15

The pulse of the elephant is—

44 beats per minute, in health.
90 to 100 „ „ disease (generally).
70 to 80 „ „ fever.

The teeth are eight in number, four in each jaw; at 70 years of age the front side teeth fall out.

Inflammation of the cellular membrane may be brought about by goading the animal on the forehead (instead of behind the ear) by the ānkūs.

For hardening the feet for travelling over rough ground, the two following recipes† are given, either of which may be used:—

No. 1.	No. 2.	
Wax, any quantity.	Chirkīn	Any quantity of each.
Chūnā „	Mahpul	
Mansal „	Tinga Ulde	
Honey „	Uldha	
Dried spleen of any animal.	Kuttha	
	Geti Supārī	
	Mohar	
	Shaoth	

* See also—Evolution of Man, by Ernst Haeckell, 1879, Vol 2, page 420.

† Sergeant Russell, Commissariat Department, says that the best mixture is—

	Sirs.	
Stockholm tar, ...	2	Mix hot, wash the feet, apply every night.
Hog's lard, ...	1	
Resin, ...	½	
Venice turpentine, ...	1	
Bees wax, ...	1	

The cost is 12 annas per elephant.

The elephant's head and forehead should be defended from the sun by a white covering of spongy nature. The toe diseases—

Ag'n bão,

bão ka marz, otherwise dāgh ka marz, or pipsar ka marz,

are engendered directly by exposure to the sun.

When suffering from worms, an elephant eats 20 to 24 lbs. of siliceous earth; purgation follows in twelve hours; worms are then passed dead.

It appears that there is nothing saline in its nature; and that the effect is produced mechanically on a certain state of the alimentary canal.*

By Act VI of 1879, *published in the "Gazette of India" of the* 19*th April* 1879, *Part IV, page* 130, *wild elephants in India are preserved.*

No one shall kill, injure, or capture any wild elephant unless—

(1) in defence;

(2) when such elephant is found injuring houses or cultivation, in the vicinity of any main road, railway or canal;

(3) as permitted by license under this Act.

Every elephant captured, and the tusks of every elephant killed (in contravention of this Act), shall be the property of Government.

The Collector, or Deputy Commissioner, may, under this Act, grant licenses to kill and capture; but the license shall not authorise trespass. The Local Government may, subject to the control of the Governor General in Council, make rules under this Act.

Whoever transgresses the condition of this Act shall be punished with a maximum fine of Rs 500 for each elephant; whoever breaks a condition of a license, with a maximum fine of Rs. 500 and forfeiture of license.

Any one convicted of a second offence, shall be punished with imprisonment which may extend to six months; or with fine or with both.

CALCUTTA:
3rd April 1879.

* See pages 253, 258, 280 and 284.

Report on the Transporting of Elephants by Railway.

In its telegram No. 3997R. of the 27th September 1878, the Government of India desired that nine elephants, for the conveyance of a heavy battery from Morar to the North-Western Frontier, should be sent from Dholepur to Multan.

In October 1878, an experiment as to the possibility of carrying an elephant by railway was partly carried out at the Howrah station of the East Indian Railway.

As shown in *Plate* IV., a cattle-wagon was prepared, and an elephant of 7½ feet stature carried in it for a distance of 1½ miles.

In the first instance, the beams were simply bolted together; but, on its being found that the bolts were bent by the pressure exercised by the animal, they were notched as well as bolted. This arrangement served well. The animal exhibited terror by bellowing; and, on passing under the Howrah overbridge, endeavoured vainly to seize it. This circumstance suggested the need of a roof, which was at once put over that part of the wagon where was the elephant's head.

The parts of the wagon which can be reached with the trunk were studded with spikes. The animal is thus prevented from wrenching the beams out of their places.

The experiment, so far as it went, was considered so satisfactory, that Major Kinloch, Deputy Assistant Quartermaster General, in his letter No. 911S. to the Quartermaster General in India, reported—

"It has been found perfectly practicable to convey elephants in ordinary cattle-trucks; there was absolutely no risk, even when the elephant was startled by the whistle of engines purposely sounded quite close. The truck was taken under bridges, started and stopped abruptly, and in fact subjected to every test that could be thought of.

"Once secured, an elephant is absolutely powerless to injure either himself or the wagon." *

In this office letter No. 2814 of the 15th October, I expressed the following opinion:—

"The experiment, so far as it was carried out, was successful; but I do not consider from what was done that it can be concluded that elephants can safely be carried by railway. The distance, 1½ miles, over which the animal was carried was insufficient as a test. If, while traversing a distance of 100 miles, he neither damaged

* In this Note (pages 291, 292 and 297) it will be seen that the animal was in this way most imperfectly secured; and, that great risk was run.

himself nor the wagon, he might ever after refuse to re-enter his wagon; and this would cause great trouble."

In its letter No. 776R. of the 18th February 1879, the Government of India desired—

"that Captain Clarke, R.E., should prepare and submit a report on the proposals for carrying elephants by railway in ordinary cattle-trucks, together with an estimate of the cost of alterations."

Arrangements were accordingly made with the Commissary General, Calcutta, and with the East Indian Railway, for the carrying out of an experiment, at Howrah station, on the East Indian Railway.

On the 1st April 1879, at 7-30 A.M.—

Two elephants were brought up to the goods siding near the passenger-station. One of the animals refused to enter the wagon; she knelt down and examined with her trunk the under side of the wagon floor; bellowed, slavered at the mouth, made water, circled about the place; and, in spite of every endeavour, resolutely refused to set her foot in the wagon.

On the same day, the other elephant—

"Titus," a small trusker, 7 feet in height, was brought up to the wagon; and after some persuasion, induced to enter; but when in, he could not be properly secured with the chains, which the elephant-drivers had brought with them. This was due partly to the chains not being exactly fitted to the work; but, chiefly to the stupidity of the men.

It may be noted that, through some accident, no officer, or non-commissioned officer, of the Commissariat Department was present at the trial; and consequently failure only could be expected, the men of the East Indian Railway not being familiar with the working of these animals.

This experiment occupied more than three hours.

On the 2nd April 1879, at 8 A.M.—

The Assistant Superintendent, Carriage and Wagon Department, East Indian Railway,
Captain Patch, Deputy Assistant Commissary General,
Captain Engledue, R.E.,
Lieutenant Johnstone, R.E.,
A Sergeant of the Commissariat Department,
Several supernumerary elephant-drivers,

being present, a second trial of the same two elephants, at the same place, was made.

As on the experiment of the 1st April, the female elephant resolutely refused to enter. As there was little time to spare, no great effort was made to persuade her. The tusker "Titus" marched, without hesitation, into the wagon; but, notwithstanding the presence of Captain Patch and the men of the Commissariat Department, every effort to secure him properly with chains was in vain.

The statement made by Major Kinloch, in his letter No. 911S., is truly applicable—

"It is absolutely necessary that the elephant should be secured with as little noise and fuss as possible. If men are properly instructed beforehand, the operation should be completed in a few minutes."

The elephant was at length removed. This trial lasted more than three hours. It was resolved that the wagon should be slightly altered, so as to allow of greater latitude in the placing of the beams; and that chains wrought in a proper manner should be used.

On the 7th April, at 6 A.M.—

Colonel Keer, Assistant Commissary General, Calcutta,

The Assistant to the Superintendent, Carriage and Wagon Department, East Indian Railway,

Inspector Boseck, Carriage and Wagon Department, East Indian Railway,

Conductor Russell, Commissariat Department,

5 elephant-drivers,

5 men of the Carriage and Wagon Department, East Indian Railway,

being present, a third trial was made. A set of elephant wagon chains, which had been made at my order by the Howrah Foundry Company, was used.

The tusker "Titus" marched with little inducement into the wagon, and, so far as the arrangements of the wagon permitted, was secured in a period of three hours.

At 9-5 A.M. the elephant wagon was attached to No. 49 van goods-train, the intention being to take the animal to Burdwan and back.

But even while the wagon was being shunted to be attached to the train, it was seen that the animal was insufficiently secured; and when the train began to move off, the animal damaged with his tusks, the side of the wagon and ripped off the roof on the left side.

Though the foot-chains had been pulled as taut as possible, he managed to get some slack, and was thus enabled to raise himself partly on his hind-legs in a very dangerous position. It was unanimously agreed that the animal could not travel in this manner, and the wagon, after going a few yards, was detached.

It was resolved that a chain collar should be made with three chains attached to it: two leading to the left and right front corners of the wagon, and the third to a ring-bolt fixed in the wagon floor immediately below the head. These three chains, being hauled taut and secured from the outside, would prevent the animal from dangerously moving his head.

On the 14th April 1879, at 7 A.M.—

the same persons being present as at the third trial,

a fourth trial took place—

Two elephants were marched up to the wagon; both, with reluctance, and under compulsion, entered the wagon. The larger of the two, a female elephant, "Hannah" by name,

7½ feet stature.
2¼ years a captive.
2 tons 1 cwt. 7 lbs. in weight.

was, after some delay, finally secured in the wagon.

The elephant wagon was then drawn by a pilot-engine through the Howrah yard to the end of the "two-mile siding" and back to the goods-shed.

The composition of the train was—

Locomotive No. 139,
5 empty covered goods wagons,
Elephant-wagon No. 230, a low-sided wagon,
A brake-van.

Every locomotive in the yard whistled, in order that the effect of the clamour upon the beast might be seen.

On the arrival of the train at the goods-shed, Howrah, the animal was released and taken out; she was then invited to re-enter, which she did at once. This experiment was successful; but it was seen that there was still a dangerous movement of the legs (in spite of the 4 foot-chains), which it was decidedly necessary to restrain.

It was resolved that a ring-bolt should be fixed between the fore-feet, and another between the hind-feet; and that the chain connecting the anklets of a pair of feet should be passed through the ring of each bolt. This arrangement would prevent, to any dangerous degree, vertical, or horizontal, motion of the feet.

On the 15th April 1879, at 7-30 A.M.—

the same persons (save Colonel Keer) as at the fourth trial being present,

a fifth trial took place—

The same two elephants were brought up to the wagon; both without difficulty successively entered and came out of the wagon. For the actual trial, the elephant "Hannah" was selected and secured in the wagon in about half an hour.

At 9-30 A.M. a special train composed as follows:—

Locomotive No. 270,
Tender,
First class carriage No. 860,
Elephant-wagon No. 230,
Low-sided wagon No. 499,
Brake-van No. 168,

was drawn up.

It left Howrah at 10-10 A.M.
„ arrived at Chandernagore 10-55 A.M.
„ „ Pandooah 11-55 A.M. (38 miles from Howrah).

The speed between Howrah and Chandernagore (between which places no stop was made) was 28 miles per hour, and this rate of speed was maintained throughout the journey. Water was thrown over the elephant's back at—

Chandernagore, Hughli, Mugra, Pandooah } on the way up.

With as little delay as possible the train left Pandooah and reached Howrah at 2 P.M. The total distance the animal was thus conveyed by rail was 76 miles.

This fifth trial was entirely successful.

The lengths and weights of the parts of the elephant-wagon chains are as follows:—

Fore-feet—		
2 anklets, each 40 inches in circumference, ...	} 30	seers.*
1 chain, connecting the pair of anklets, 14 inches,...		
2 tethering chains, each 12 feet in length, ...		
Precisely the same as for the fore-feet, ...	30	„ *
Neck gear—		
Collar, 7 feet in circumference, ...	} $89\frac{3}{7}$	„
3 chains, each 12 feet long, ...		
Total weight of elephant-wagon chain gear, ...	$149\frac{3}{7}$	„

The chain-collar and anklets should be covered with stout leather and padded with jute.

The chain-gear will be left attached to the elephant-wagon, with which

* See foot-notes to pages 298 and 299. It would be better to use, in part, the ropes belonging to the elephant-gear. Expense will be saved.

all these trials have been made, so that the wagon will be complete as a model.

The cattle-wagon, which has thus, successfully, been converted into an elephant-wagon, is marked as follows :—

East Indian Railway No. 230,

	Tons.	Cwt.	Qrs.
Weight, ...	6	17	2

The cost of an elephant-wagon is as follows :—

	Rs.
The cost of cattle-wagon, ...	1,600
„ elephant fittings, ...	160
„ „ wagon chains (gear), ...	63
Total cost of elephant-wagon, ...	1,763

The time required—

	Days.
to fit up one wagon would be	1
to make the elephant-wagon chains	2
if necessary, forty wagons could be prepared in... ...	10

Plate IV., attached to this report, shows sufficiently plainly the general arrangement of the parts of the elephant-wagon.

The following changes have been introduced :—

(*a*). In place of 3 longitudinal beams on either side of the animal, there are now 4 beams (only 3 are represented in the *Plates*); but, I believe 3 are sufficient.

(*b*). The breast bar and ridge-pole are free of all spikes.

(*c*). Three ring-bolts have been fixed in the floor :
one for the centre neck chain.
one between the fore-feet.
one between the hind-feet.

(*d*). The breast bar may conveniently be fixed, while the hind bar may (without being lifted) be made to slide, horizontally, forwards or backwards ; a stout piece of wood should be strongly bolted to the side of the wagon far to the rear to serve as an abutment ; horizontal distance blocks, kept in position by two bolts through the wagon side, will communicate the stress from the hind bar to the abutment-piece. By this arrangement, much labour may be saved in shifting the beams.

There are on the East Indian Railway—

53 cattle wagons }
106 coke „ } which could be converted easily into elephant wagons.*

When travelling, the elephant will certainly need some protection from the sun : this may be afforded by—

* According to the Report of the Superintendent, Carriage and Wagon Department, East Indian Railway, for the half-year ending December 1878, page 5—
The cattle and coke wagons are to be rebuilt as covered goods.
If this be so, early orders are necessary.

(*a*) putting his jhúl on his back.

(*b*) stretching a tarpaulin over the ridge-pole of the wagon.

He should also, in hot weather, be washed; and this, in the case of a train of elephants, will be somewhat troublesome. At Pandooah it was found difficult to get the water from the water-column properly directed upon the animal's back, as the mouth of the crane itself is considerably below the level of the elephant's back, and the hose being short (5 or 6 feet in length), and torn, most of the water spurted out uselessly in jets through the holes in the hose.

A piece of sound hose 9 feet in length (carried with the elephant-train), which could be attached to the water-column of the Railway station where it was proposed to water and wash the animals,—would be very effective.

The elephant's clothing and all his gear can go with him in his wagon; and a certain amount of fodder can also be carried. With the beast's evacuations, and the water which is sluiced over him, it must be remembered that the wagon gets into a dirty state.

To embark a single elephant, or a large number forming a train, parties of men, each numbering 10, will be required.

For a train-load two such parties would be required, the composition of which would be—

Five elephant-drivers.

Five men of the Carriage and Wagon Department.

With each train should be an *intelligent* and experienced Sergeant, or Warrant Officer, of the Commissariat Department.*

For the elephants themselves, it would be better that they should travel at night; but all things considered, it is safer that they should do so by day only, and rest at night; this arrangement will also save much trouble as to feeding and watering.

The elephant "Hannah" has been a captive only two years. It is said that elephants are not fully tamed till they have been three years in captivity.† In Upper India, the elephants are caught about Dacca, trained in Bengal, and then sent up country. It is thus certain that the transporting of elephants, if successful at Calcutta, will be successful

* If a train of elephants be despatched to the Frontier, I would suggest, with the permission of the Commissary General, that Sergeant Russell, Commissariat Department, Calcutta, be placed in charge, and that he receive Rs. 100 as compensation for the trial, trouble, and responsibility of conveying the animals.

† See page 284 of the Note "on elephants."

everywhere, as the elephants at Calcutta are for the most part imperfectly trained and tamed.

Elephants belonging to batteries are highly trained, and no difficulty need be anticipated as to embarking them generally in trains.

Male elephants, by reason of their tusks, their superior size, their greater boldness, and their liability to getting *mast*, will probably be everywhere more troublesome to manage, as to embarking, than female elephants.

It would be well if the Commissariat Department were to keep a list of all elephants which could easily be transported by rail. At Calcutta, the entering a railway wagon, the being secured in it, and disembarking from it might form part of the elephant's training and education.

It is said, in various books, that the elephant attains a stature measured at the shoulder of 10, or 11, feet.

Mr. Sanderson, the Superintendent of the Khedá at Dacca, however, declares that there is probably no elephant in India measuring 10 feet, and that the largest that he has seen is $9\frac{10}{12}$ feet.

Considering now the diagram of the cattle-wagon converted into an elephant-wagon, it will be seen that (the maximum moving dimensions being reached) the height from wagon-floor to under-side of ridge-pole is 9 feet only; and that without lowering the wagon-floor, greater height cannot be obtained.

Elephants of limited (not of maximum) stature only can, therefore, be carried in cattle trucks.

It is, however, probable that, in the Commissariat Department, the average height is $7\frac{1}{2}$ feet only; and, that the maximum stature is rarely attained.

As regards undue oscillation of the elephant-wagon, on account of the height of the centre of gravity of the live load above the floor, no apprehension need be entertained.

	Tons.	Cwts.	Qrs.
The dead weight of the wagon with fittings is, ...	6	17	2
Floor chains and anklets, ...	0	0	3
Total, ...	6	18	1
Weight of an elephant $7\frac{1}{2}$ feet stature, ...	2	1	7

The actual live load, compared with the dead load, is in this case very small. When the wagon carries 10 tons of grass (as it safely may) the centre of gravity would then be as high (as in the case of the elephant), while the load carried (instead of being less than) would greatly exceed the dead weight of the wagon.

Appended to this report is a diagram (not reprinted) of a new form of wagon designed specially to carry two elephants, but fitted to carry goods generally.

This design was submitted by the Superintendent, Carriage and Wagon Department, East Indian Railway, as it was at one time feared that the transport of elephants could not be effected in cattle-wagons.

It will be seen that the floor, like the fire-box of the locomotive, is only 9 inches above rail-level.

It may be observed—

that the space of $4\frac{1}{2}$ feet for the breadth of each elephant is scanty; that the actual height from floor-level to architrave of door-way being $9\frac{1}{4}$ feet only, an elephant of maximum size could no more enter this than he could an ordinary cattle-wagon; and that the total length, $10\frac{1}{2}$ feet, is very scanty.

The back of an elephant is much higher than his shoulder; but his head is on the same level as his shoulder.*

Bearing in mind the remarks in page 296, I see nothing in the construction of this form of wagon to recommend. It is doubtless more costly to build.

From the working Time-table of the East Indian Railway, the weight of a goods train (ruled by the minimum load) between Howrah and Delhi is 400 tons.

A train carrying elephants from Howrah (or any station east of Delhi) to the Frontier would be composed as follows:—

		Tons	
Locomotive, ...	} =	56	
Tender, ...			
x elephant-wagons, ...	=		$10\frac{1}{2}x$†
1 Composite carriage, ...	=	$7\frac{1}{2}$	
1 Brake-van plus load, ...	=	8	
Total weight tons,		$71\frac{1}{2}$	$10\frac{1}{2}x$

* A *hog-backed* elephant, standing 8 feet at the shoulder, will measure $8\frac{3}{4}$ feet at the highest part of the back.

	Tons.	Cwt.	Qrs.
† Weight of wagon with fittings, ...	6	17	2
,, elephant-wagon chains, ...	0	2	$2\frac{1}{2}$
,, elephant-gear, ...	0	11	$1\frac{1}{2}$
,, elephant ($7\frac{1}{2}$ foot) stature, ...	2	1	7
Total,			

or say with attendants and fodder, $10\frac{1}{2}$ tons.

This will allow for extra weight in the case of a large elephant.

Then—

$$71\tfrac{1}{2} + 10\tfrac{1}{2}\,x = 400 \text{ tons.}$$

$$\therefore\; x = \frac{328\cdot5}{10\cdot5} = 31\cdot2 \text{ elephants per train.}$$

It is believed that attempts were made by—

The Great Indian Peninsula Railway,
The Scinde, Punjab and Delhi Railway,

to carry elephants by railway, and that the idea of carrying them was abandoned, it being found impossible to induce the animals to lie down in the wagon.

It has been shown in page 296 of this Note, and also by actual trial, so far as the height of the centre of gravity is concerned, that there is no need to lower it by forcing the elephant into a recumbent posture; and further, it may be remarked that an elephant cannot remain in a sitting posture for a length of time.

Mr. G. P. Sanderson, in a demi-official letter of the 12th April 1879, Camp, Garo Hills, in reply to one written to him about the 1st April, says—

The transporting of elephants by Railway is a matter which I have often thought of ; and I venture to think it ought to be carried at all costs to a successful conclusion, as the power of conveying elephants by rail would enable the Government of India to introduce very great economy. Elephants might be greatly reduced in number throughout India ; and be kept where fodder was plentiful.

I have seen the wagon, of which you sent me plans. It seems to me to be well suited to the work, except as to the method used for securing the elephant, and as regards the hoarding about the elephant's head.

I would secure the fore and hind-feet to two ring-bolts let into the wagon-floor.* The *ropes*, with which every elephant is provided, could thus be utilised.†

The hoarding, I think, is unnecessary ; the effect upon the animal of seeing bridges and trains should not be considered.‡

An elephant cannot be secured in any other position than standing. Kneeling is very irksome, and could not be maintained without extreme suffering and risk of damage.

The wagon-floor should be on a level with that of the platform, or higher, *not lower.*

* This was the plan adopted ; further, the neck was secured by chains passing from a collar to a third ring-bolt in the floor. (*See* pages 291 and 292).

† It would probably be better to use ropes than chains, as galling would be less likely to occur ; besides, expense would be saved.

‡ When the neck is secured with chains, the hoarding may be unnecessary ; but otherwise not. An elephant, with his head free, could seize water columns, &c. The hoarding serves also to protect his eyes from dust and sparks ; and his head from the sun's rays.

Litter should be strewn on the wagon-floor. A determined mahâwat will forcibly make an elephant do things which it would not do for others.

The maximum running height of the wagon appears to be 9 feet 2½ inches, which would be ample for *ordinary* elephants. As to females, not 1 in 50 exceeds 8 feet at the shoulder.*

A crane should be employed to hoist any refractory elephants into the wagons.

There seems to be no reason why 50 elephants should not be started upon a journey of any length at a day's notice, from any depôt where they may be kept; they need never leave their wagons *en route*, and might be kept under shelter during the heat of the day.†

The cost of the trials, relating to the transport of elephants by railway, now concluded, is as follows:—

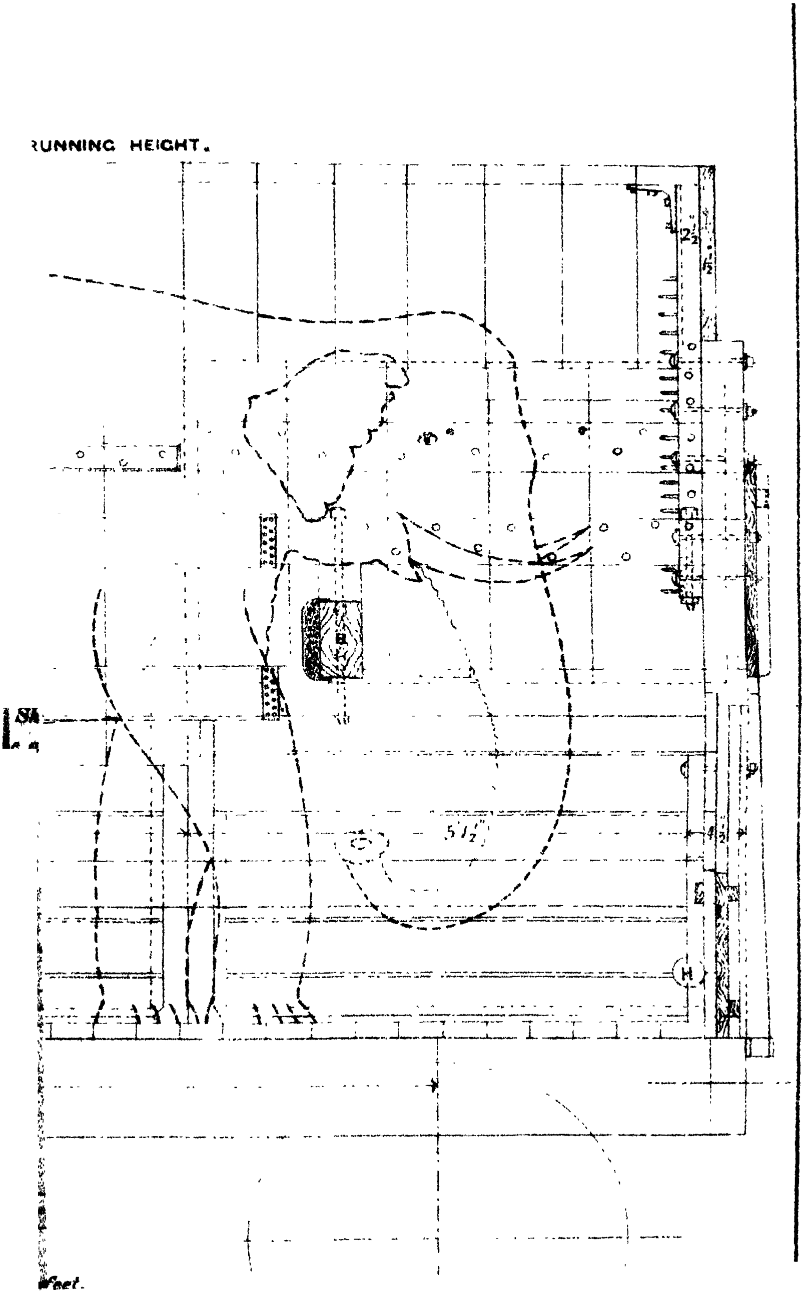
	Rs.
Fittings of cattle-wagon No. 230, ...	160
Elephant-wagon chains, ...	63
Haulage from Howrah to Pandooah and back, at Rs. 2½ per mile,	190
Bonus to Sergeant Russel and Inspector Boseck, ...	100
Total Rs., ..	513

H. W. C.

CALCUTTA:
16th April 1879.

* This would allow for a hog-backed beast, which would stand 8¾ feet at the centre of the back.

† In page 298 it will be seen that only 32 elephants can, in one train, be carried. Till some experience has been gained in the transporting of these animals, it would not be well to journey by night.—H. W. C.


RUNNING HEIGHT.
5 1/2"
B
H
Feet.

No. CCCXI.

EXAMPLES OF SOLID IRON SCREW PILE BRIDGES.

[*Vide* Plate.]

By Col. C. A. Goodfellow, R.E.

Built from 1871 *to* 1873 *on the Bellary-Karwar Road, in the Dharwar and Kanara Districts, Bombay Presidency.*

The general design and construction of these bridges is sufficiently explained by the accompanying *Plate*, but some explanation of details is perhaps necessary.

Sirguppi Bridge.—A temporary bridge merely intended to span the very treacherous and muddy bed of the fairweather stream, the piles were only 2 inches in diameter; round bar iron fitted into the cut off screw bases of the old style of telegraph post socket, in use twenty years ago; screwed down by spanners 6 feet long; the piles whilst being screwed, being kept in position by means of a guide frame with a platform, on which the men screwing down worked; the bridge was built in just one month, having cost Rs. 3,920, it was opened for traffic in October 1871, and was washed away in September 1872; this nullah has a fall of 18 feet per mile, and a very bad reputation in the country; on this occasion it took the bridge, (owing to their being a junction of two nullahs just above the bridge, and to the fact that only one of them was in flood,) almost longitudinally and completely overthrew it; all the woodwork was carried away, but not one pile was drawn, though all were bent and some twisted in an extraordinary manner. The resistance this bridge made, induced Government to consent to others of full height and stronger construction, but similar in principle, being built on the same road on the black soil plain of Dharwar; and two such were built in 1872-73, one at *Nalowda*, 13 miles east of Hubli, and at *Budrapur*, 18 miles east of Hubli.

Nalowda Bridge.—Twelve spans of 16 feet; piles 2½ inches in diameter; commenced in June 1872; opened for traffic in April 1873; cost Rs. 19,358, or Rs. 100 per foot of waterway. (*See Plate*).

Budrapur Bridge.—Ten spans of 16 feet; piles 2½ inches diameter; or Rs. 104 per foot of waterway.

Neither of these bridges were built precisely as designed; in construction the masonry abutments were made of massive granite ashlar, with wings, instead of dry stone as originally intended, and the struts (A, A, A, and the *lower* cross braces B, B, B) were added. Also when the piles had been screwed down and the bridges were nearly completed, excavations were made about piles of each pier down to the hard bed of marl, into which the piles were screwed, and a wall of concrete was put in round the piles. Also for the single fender piles of the original design, were substituted triangular fenders, each formed of three teak spars joined by cross-bars and buried in a concrete foundation; it is doubtful if these alterations, whilst adding to the cost of bridges, were improvements; the fall of the Nalowda nullah is 10 feet per mile, that of the Budrapur nullah 13½ feet per mile; both these nullahs are subject to sudden and heavy floods, and one object in using the light piles was to evade scour.

Both the bridges were severely tested in September and October 1874, when the floods were just awash with the road, that is 3 feet higher than the presumed highest flood level, the *Nalowda* bridge was uninjured, though there was some scour of the bed, but at the *Budrapur* bridge, the bed near the bank was scoured out down to the hard marl, leaving the walls of concrete round the piles bare; by the action of the ordinary monsoon floods the bed soon silted up to the usual level, and no harm occurred to the eight piers and their superstructure; the abutments, however, or more properly speaking the masonry terminations of the embankments, were scoured out and fell, bending the four piles of one abutment, and breaking off one pile of the other abutment; three fender piles were also carried away and one down-stream strut, and three piles of one pier next on abutment were a little bent by the impact of a floating log, part of the timbers of the old bridge, carelessly left on the up-stream embankment, and jammed by the falling masonry; the damage done was quickly repaired by rebuilding the masonry and straightening the piles with a "jim crow;" had the masonry been of dry stone, as designed, it is unlikely that any injury would have occurred to the bridge itself from the fall of the abutments; they would have fallen sooner no doubt, but that would the sooner have relieved the pressure to which the heavy scour was due; and as for the massive fenders there is little doubt that they were the chief cause of the scour.

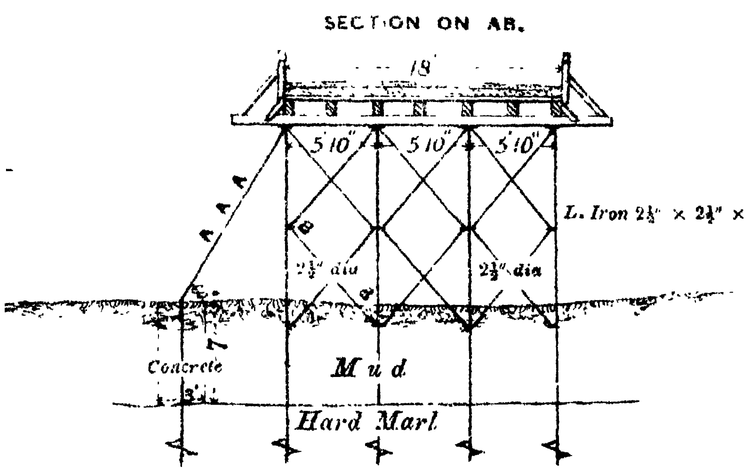
Chendia Bridge.—Two spans of $25\frac{1}{2}$ feet on the skew on the same road, but six miles from Karwar on the coast. This bridge (exclusive of the cost of the 12 piles, which happened to be available from another completed work at Karwar, a pier) cost Rs. 12,600, and was completed ready for traffic in five months, though the bridge simply, that is the iron and masonry work, did not take more than three months to finish, the other two being taken up by delays connected with the approach, the piles of this bridge are 6 inches in diameter, and were also screwed down without the aid of any machinery other than capstan collars and crab winches worked by hand.

The peculiar advantage of the use of solid piles is rapidity and ease in getting in foundations, an advantage which under certain circumstances is all important.

From recent accounts received, the small $2\frac{1}{2}$ inch piles of the Nalowda and Budrapur bridges are as sound as ever, though some of the woodwork has required renewal.

Bombay, C. A. G.

8th April, 1879.


SECTION ON AB.
18'
5'10"
5'10"
5'10"
L. Iron 2½" × 2½" × ½"
2½" dia
2½" dia
Concrete
3'
Mud
Hard Marl

No. CCCXII.

EXCERPTA FROM NOTES ON THE TRANSPORT BY RAIL OF TROOPS, HORSES, GUNS AND WAR MATERIAL FOR THE ARMY IN AFGHANISTAN DURING 1878-79.

BY DAVID ROSS, ESQ., *Traffic Manager, Scinde, Punjab and Delhi Railway.*

Dated Lahore, 25th July 1879.

"2. Since the movement towards Cabul commenced on the 30th September 1878, when the first Regiment, the 12th Khelat-i-Ghilzies, proceeded, until the return of the Punjab Chiefs' Contingent—the last special with the Maharajah of Patiála's cavalry passing Lahore on the 5th July—the grand total amounted to—

1,88,280	Troops and Followers.
23,142	Horses, Ponies and Mules.
147	Guns.
7,553	Bullocks.
973	Camels.
13,47,004	Maunds, Commissariat and Military Stores.

"5. * * * a number of Regiments were concentrated at Mean Meer and Mooltan, &c., in the first place, and they remained there for a few weeks before proceeding to the front. Such troops, of course, are reckoned twice. Each despatch involved the same amount of work to the Railway authorities, as if the Regiments had gone at first right through to their destination.

"6. The maundage only shews the stores despatched under warrant. The greater portion of the grain, &c., for the troops was booked by traders, so the figures given, represent only a small proportion of the Military stores really forwarded by rail.

"9. Although Tro·ps and Military stores had priority of despatch, in very few cases, comparatively, was the traffic of the line interfered with or delayed in transit.

"11. In order to transport the troops in carriages, we had to substitute covered goods wagons for the ordinary passenger traffic, and with the removal of a few panels at the sides and ends of these vehicles for ventilation, the natives were quite satisfied with this mode of conveyance.

"12. These wagons similarly treated with the addition of two breast bars fixed laterally across, were used in the carriage of cavalry; eight horses being comfortably carried in this manner, with their heads in the centre, and room between for syces, provender and harness.

"13. In any case of emergency, these wagons with wooden planks fixed for seats could be easily adapted for the transport of European infantry, but Sepoys seem to prefer them without alterations, as they are thus enabled to squat down or recline on their bedding. From 30 to 35 natives can be comfortably carried in the goods wagons during the cold season, and not more than 30 in the hot weather. Brackets could also be fitted up at the ends to hold lamps for night travelling.

"17. * * * With our goods rolling stock converted as proposed, we should be able to concentrate on Lahore from the Mooltan and Delhi directions, without assistance from other Railways, a force equal to—

3 Batteries of Artillery,
2 Regiments of Cavalry,
3 Regiments European Infantry,
5 „ Native „

or in all about 7,000 men of all arms every 24 hours.

"23. To provide for the conveyance of 7,000 troops per day in the proportions of the different arms of the service as referred to in para. 17, the following are the details in regard to our rolling stock required:—

Ghaziabad to Lahore 15 *Trains required.*

15	1st Class or Composite Carriages for	Officers.
129	2nd „	Men.
65	3rd „	Followers.
150	Vehicles, ...	Horses.
24	Trucks, ...	Guns.
121	Wagons, ...	Baggage.
8	Powder-Vans, ...	Ammunition.
15	Break-Vans.	
527	Vehicles.	

"24. On the Mooltan Section, the June bill makes provision for 11 trains each way daily, which would enable an additional 73⅓ per cent. of troops to be conveyed in similar proportions. The stock required would be as follows:—

11	1st Class or Composite Carriages	for	Officers.
96	2nd ,,	..	Men.
48	3rd ,,	..	Followers.
112	Vehicles,	..	Horses.
91	Wagons,	..	Baggage.
18	Trucks,	..	Guns.
6	Powder-Vans,	..	Ammunition.
11	Break-Vans.		
393	Vehicles.		

"25. But as a similar number of vehicles would require to move in the opposite direction, our total requirements as to rolling stock should be :—

(Here follows table giving numbers double the sum of the two preceding).

"28. As a large proportion of the troops must come from down country or the sea-board direction in Foreign Companies' vehicles, no strain such as contemplated in the foregoing would ever be put on this line in regard to the supply of stock.

"58. To show that the carrying powers of our line as stated in the foregoing, are not over-estimated, I may mention that in connection with the recent Hardwar Fair during 18 days in April, we carried about 250,000 pilgrims in addition to the ordinary traffic of the line, or on an average nearly 14,000 per day; of course to do this, all descriptions of vehicles were employed—goods wagons, covered and open, cattle trucks, &c. It can, however, be understood that the transport of these pilgrims was an easy matter, as compared with the conveyance of troops."

D. R.

No. CCCXIII.

EXCAVATING AND UNDER-CUTTING MACHINES FOR SINKING WELLS AND CYLINDERS THROUGH CLAY AND SIMILAR HARD SOILS.

[*Vide* Plates I and II.]

BY E. W. STONEY, ESQ., *B.C.E., M. Inst. C.E.*

THE Helical Excavator which was described in July 1875, Article No. CLXVII., Professional Papers on Indian Engineering, though remaining in principle the same, has been improved in constructive details and methods of working.

The openings in the bottom and sides are now made as large as the size of each machine permits, so as to facilitate filling, and the square holes at top and bottom are connected, and enclosed by a pipe, which prevents any of the contents of the excavator from either escaping through them, or touching the iron rod by which it is worked.

The most suitable size for hand work has a circular body 2 feet 6 inches in diameter by 11 inches high, this contains 4½ to 5 cubic feet, weighs when empty 368 lbs., and when full of clay about 876 lbs., and makes a cylindrical hole 3 feet 6 inches to 4 feet in diameter.

The above size will excavate from 100 to 150 cubic feet of clay daily, from a depth of 70 feet if worked by manual labour; and about three times as much if a steam winch be used to raise and lower it; machines of this description up to 3 feet 6 inches in diameter have been successfully used, both in India and Ceylon, in sinking wells of from 6 feet to 12 feet in diameter, to depths of from 40 feet to 90 feet.

An excavator 2 feet 6 inches in diameter is about the largest size that a 2-inch square iron rod is strong enough to work in stiff clay; and as long rods of larger section would be too heavy and troublesome for use in ordinary works, the Enlarger about to be described has been designed to make large holes, when worked by the same 2-inch rod used with the Helical excavator.

The Under-cutter has been similarly designed for use with 2-inch rods, with a view to obviate the necessity there exists, for using inconveniently large loads, to sink wells through stiff material, when the soil beneath their curbs is not removed.

Fig. 2, *Plate* I. is a plan; and *Fig.* 3, *Plate* I. an elevation of the "Enlarging excavator," designed by the author to increase the size to a cylindrical hole made by the Helical excavator, up to the full size of the interior of the well or cylinder in which it is used.

This machine is of very strong and simple design, formed of a pair of semi-circular L iron ribs CC, joined by iron distance pieces, which form square holes for the rod R to pass through, and separate the ribs sufficiently to allow the arms A and B to work between them. These arms are made of angle or channel iron, according to the size and strength required, their lower ends being pivotted, while their upper ends are expanded into double-edged cutters as shewn; in the vertical webs of the ribs holes 1 inch diameter and 2 inches pitch are drilled, a single similar hole being drilled in each of the arms A and B.

These arms may be secured at inclinations varying from almost horizontal to nearly vertical, by bringing the holes in them opposite each pair in the ribs, and then passing a bolt x through each.

It will be at once seen that the diameter of the cut made by these arms can be increased or diminished by successive increments, by merely moving them in their respective quadrants, and that when they revolve the hole of least diameter will be cut by them when nearly vertical, this diameter increasing as the arms approach a horizontal position.

A hole may, therefore, be enlarged in successive cuts by means of this machine, from the diameter of the semi-circular ribs, to that of the arms when horizontal.

The cutters in which the arms terminate are made double, in order that the machine may cut revolving either to the right or left, so that by turning it as many times backwards as forwards, the rope by which it is raised or lowered, is prevented from twisting round the rod R, by which the enlarger is driven.

The following points in the design are, it is believed, worthy of notice:—

1*st*. The frame and arms can be made of any required strength.

2nd. The arms are supported for more than half their length by strong quadrants.

3rd. A great many different sized holes may be made with the same machine, and the number of these may be further increased by having two sets of arms of different lengths to fit the same body.

4th. The size of each cut may be varied to suit exactly the resistance to be overcome, so that the torsion on the bar R shall not be excessive, and be kept pretty uniform.

The mode of using the Enlarger is as follows:—

A hole about 3 feet 6 inches in diameter and 10 feet deep is first sunk in the centre of the well, by means of the Helical excavator previously described, this is then removed, and the Enlarger lowered with its arms A and B fixed for cut 1, say 4 feet 3 inches diameter; when lowered the rope O, which suspends it, is left slack, and the machine is turned round continuously backward and forward, by men at the handle H, (which can be fixed to, or taken off, the rod R at pleasure,) till cut 1 is carried to, or near, the bottom of the centre hole; this cut being finished, the machine is raised to the well top, the stud bolts x, x' removed, the arms A, B set down two or more holes, so as to make a cut say 5 feet in diameter, and the stud bolts re-inserted; this done the machine is again lowered and turned round as before, till cut 2 is complete; any number of cuts may be made in a similar manner. In *Fig.* 3, *Plate* I., the arms A, B, are shown fixed in position for cut 3, the dotted lines 1, 2 show their positions for cuts 1 and 2 respectively.

The material thus cut off drops to the bottom of the centre hole, from which it may be taken out, either with the Helical excavator before described, or Bull's dredger.

A hole may therefore be enlarged in successive cuts by means of this machine, from the diameter of the semi-circular ribs, up to that of the arms extended horizontally; and the width of these cuts may be regulated to suit the degree of hardness of the material cut, by shifting the arms one, two, or more holes at a time, the softer the material the wider the cut may be, and *vice versâ.*

The author has with one of these machines enlarged a hole 3 feet 6 inches in diameter in hard dry clay, up to 11 feet in diameter, using a rod R of 2-inch square iron, and a handle 5 feet radius driven by five men.

Enlarging machines of this sort may be made with three arms placed at angles of 120°, or with four arms at right angles to each other. When so made they are more costly than the simpler form with two arms, but would possess some advantage in being self-centering when cutting.

Figs. 8 and 9, *Plate* II., illustrate a machine which the author has designed for under-cutting wells, similar in principal to the Enlarger described, but differing from it, in so far, that means are provided for opening and closing the cutter arms from above, so that the machine may be drawn up, or let down through the interior of the well in which it is used.

The under-cutter may have either two, three, or four arms.

The lower part of *Fig.* 8 shows a two arm machine with the cutters opened almost to their full extent, while in the upper part of the same figure, the arms are closed to allow the machine to be raised to the cylinder top. The machine is formed of an angle iron frame work, and arms A, B, similar to those used in the Enlarging excavator; having in addition rods 8, 9, secured to bell cranks K, L, fixed to the backs of each of the arms A, B, and those rods terminate in a guide 13, which slides up and down the rod R, and to this guide the rope O is tied.

The whole machine is suspended by the rods 6, 7 and rope Q tied to the hook and guide 14.

By an examination of *Fig.* 8, *Plate* II., it will be seen that if the machine is suspended by the rope Q while the rope O is left slack, the arms A, B, will drop down as shown in the upper part of *Fig.* 9, and so allow of the whole machine being drawn up through the well, while if the rope Q be left slack, and the machine be suspended by the rope O, the arms will expand as represented in the lower figure, till they either touch the clay they are to cut, or the stop pins, &c., placed to limit their travel.

The mode of using the machine is as follows :—

A hole the size of the interior of the well, 8 or 10 feet deep, is first excavated in the manner already described, or otherwise.

The stop bolts are then put in position for the first cut, in the quadrant holes, and the machine lowered by the rope Q and suspenders 6, 7 ; when it reaches the bottom of the excavation, the rope Q is slackened, and the rope O hauled tight and kept so; this causes the arms A, B, to move out till they touch the clay they are to cut.

The machine is now turned round back and forward by the handle H, fixed to the rod R, and this causes the arms to cut gradually out till they reach the stop bolts, placed to limit the diameter of their cut, and by keeping the rope O tight, while the under-cutter is being turned, cut 1 will be carried right up to the well curb as shown in *Fig.* 8.

When this cut is finished, the rope O is let slack, and the machine drawn to the cylinder top by the rope Q, the clay cut out should now be dredged up, and the stop bolts moved out and placed in the holes for the diameter of the next cut, which may then be made as already described.

In *Plate* II. the under-cutting is represented as done in three cuts marked 1, 2, 3, the corresponding positions of the arms being shown by dotted lines.

In practice the number of cuts will vary with the nature of the soil cut, being few in soft and many in hard materials.

It will be seen, however, that the under-cutter just described is of strong and simple construction, and that it will make cuts of very many diameters.

The arms are placed below their frame so as to cut upwards, in order to prevent their being caught, and the machine held fast in the event of a well suddenly sinking. If this should occur, the tendency of the sinking well would be to close the arms, so that the machine could be drawn up by hauling on the rope Q.

The author, with one of these machines, undercut a hole 3 feet 6 inches in diameter, formed in stiff dry clay soil, till it attained a diameter of 10 feet 4 inches, equal to an undercut of 3 feet 5 inches all round.

The above described machines are all arranged so that they can be worked by the same 2-inch square iron bar turned by the handle H, which is made so that it may quickly taken off by turning back the screw handle *f*, *Fig.* 8, which unclamps the catch *g*, which is then turned over into the vertical position shown by dotted lines, and as rapidly put and clamped on the rod R by reversing the above process.

A platform to support the men who turn the handle H is also necessary, and this may be made in a very convenient form as shown in *Figs.* 1, 3, 8; it consists of a square frame LL, (of size suited to the wells on which it is used,) to which doors *y*, *z*, are securely hinged, these when open allow the excavator to pass up from, or down into, the well, and when closed, as in *Fig.* 8, form a level floor on which the men working the machines walk round.

In connection with this, a barrow D running on rails as in *Figs.* 1, 3, should be used, into which the Helical excavator after coming up full is discharged, and then lowered at once, the barrow being run back and its contents thrown into the river below.

In order that these machines may, when used, run freely up and down the rod R, it should always be suspended in such a manner as will prevent it from getting bent, and at the same time allow it to turn freely.

This may be conveniently done when wells are 12 feet in diameter or more, by building up portions of them E, F, as in *Figs.* 1, 3, and fixing on top of these walls a cross-beam M, in the centre of which is placed a boxed cast-iron socket J, *Fig.* 4, and in this rests and turns the gland T, formed with a rectangular hole, in which the rod R fits, and is fastened by the key K.

T, J, and M, *Fig.* 4, are provided each with a side opening, so that the rod R may, when unkeyed, be taken out without disturbing them.

On one side of M is bolted the double pulley P, through the sheaves of which the rope O or ropes O, Q, required to work the various excavators, pass, *Fig.* 1.

In small wells either the cross piece M can be supported by four raking legs mortised at foot into the frame LL, or a derrick pole used as in *Fig.* 8.

When a derrick is used to work these machines, it should be fitted with a jib J, controlled by ropes E, F, having at its extremity a double pulley P, through the sheaves of which the ropes O,Q, required to work the machines, pass.

The rod in this case should be suspended by a swivel hook S, tied to a rope G, which after passing through the sheave U is secured to the lower part of the derrick.

The pulley P should always be kept below the top of the rod R, (which may be easily done by lowering the jib J,) so that when this is turned, the ropes O and G cannot twist together.

Before commencing work the rod R should be turned round and allowed to sink by its own weight 5 feet or so, into the material at the bottom of the well, and then suspended, so that its lower extremity may have a steady guide to work in.

For depths of 40 feet or so, continuous rods formed by welding 2-inch square iron bars together, up to a length of about 50 feet, will be found most convenient; but for greater depths jointed rods are more suitable.

These rods can be put into the wells in which they are required to be used most conveniently by means of a derrick, before the wells are built high up.

Fig. 6, *Plate* I., shows a joint for use with the 2-inch square iron rods R, it consists of two pieces A and B which form a splice, held together by the screws 5, 6, and further strengthened by the socket or collar C, which is slightly tapered inside to fit the corresponding taper of A and B.

The smaller end B of the joint should be kept up, and be welded in this position to the 2-inch square bars, as shown in *Fig.* 5, these may be about 30 feet long; a bottom length of 2½ inches square iron, 15 to 20 feet long, being required to drive the excavator, which, when used with a jointed rod, requires to have holes 2⅝ inches square in it, to allow it to pass freely over the joints.

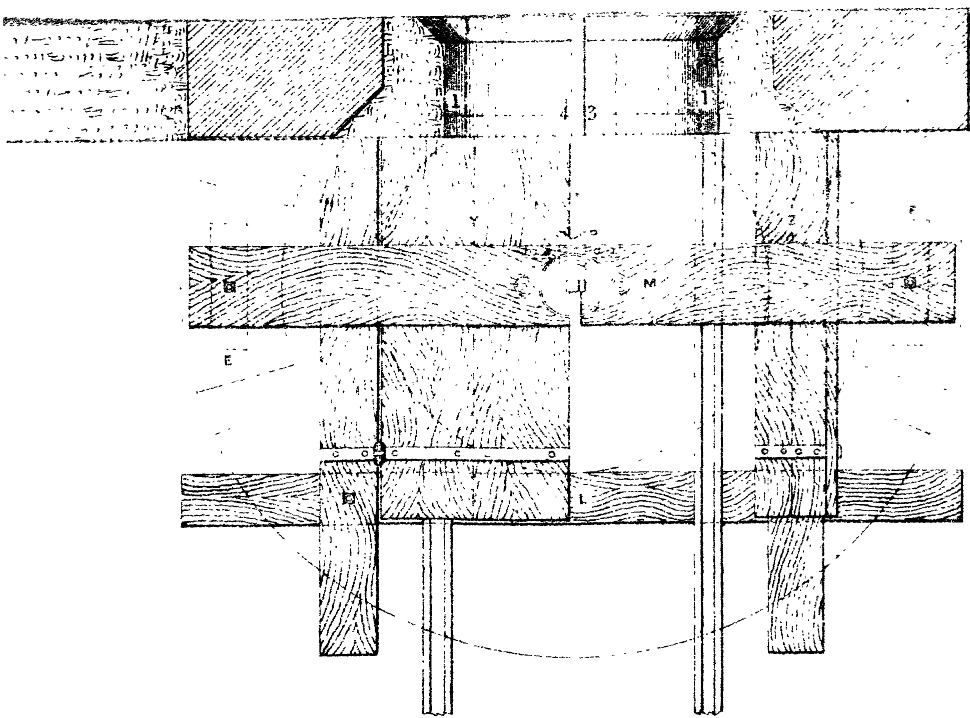
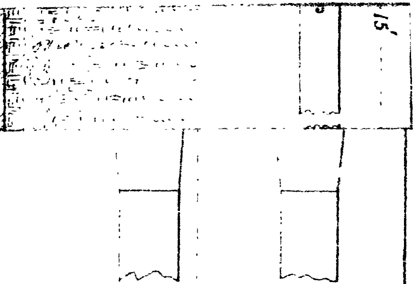
The collar C can be driven on tight by slipping the iron piece S, *Fig.* 7, down on its end; and striking that with a hammer. When the collar C has been driven home, it is secured in place by the stud screw 7; the joint and collar should be well oiled before being put together, to prevent them rusting together.

If the machines just described be used on the same work, the rod R would remain as at first placed in the well centre, and after a hole 10 or 15 feet deep had been made by the excavator, it would be taken off the rod R, and the Enlarger and Under-cutter would be put on in succession, to complete the excavation to the diameter of the exterior of the well, being worked by the same rod and appliances used for the excavator.

In conclusion, the writer trusts that the apparatus just described for excavating and under-cutting wells, when being sunk in clay, may meet with the approval of Engineers in India, who have experienced the difficulty, delay and expense there is, in getting and placing the very heavy weights required to sink wells through clay when their curbs are not undercut.

E. W. S

EXCAVATING AND UNDER-CUTTING MACHINE FOR SINKING WELLS AND CYLINDERS.

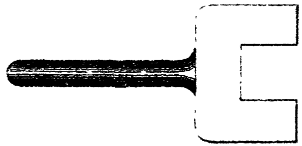


Fig. 7.

EXCAVATING AND UNDER-CUTTING MACHINE FOR SINKING WELLS AND CYLINDERS.

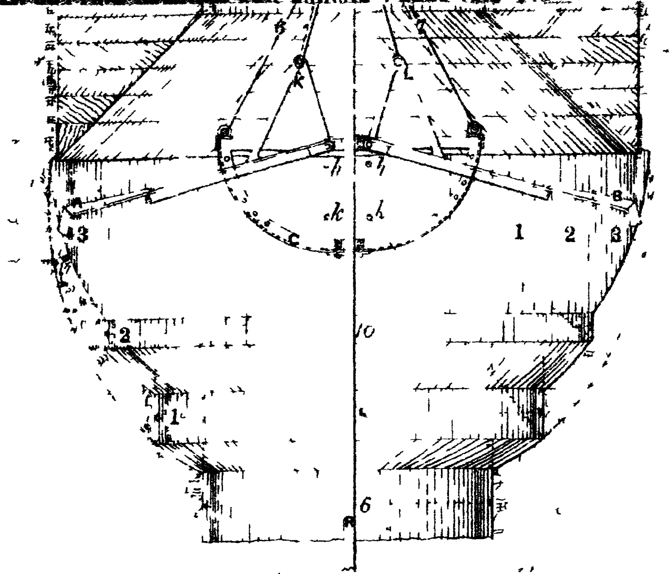
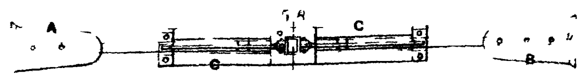


Fig 9



No. CCCXIV.

THE KRISHNA BRIDGE, NEAR KOLHAPUR.

[*Vide* Plates I. and II.]

By Major E. D'O. Twemlow, R.E., *Exec. Engineer, Kolhapur.*

This bridge is on the road from Bijapur to the coast *viâ* Kolhapur and the Amba Ghat. It crosses the river Krishna at the village of Oodgaum 24 miles due east of Kolhapur. Taking its rise in the Western Ghats close to the hill station of Mahabaleshwar, the river, on issuing from the hills, takes a southerly course parallel to the range until it reaches the bridge site about 150 miles from the source. At this point the area drained by the river is 5,000 square miles. The annual rainfall over this district varies from as much as 250 inches along the ghat water-shed, to 40 inches about Satara on the right bank, while on the eastern or left bank, the average probably does not exceed 20 inches. The width of the waterway is about 800 feet, and the depth of the river in extreme floods is 56 to 60 feet; at these times, however, the water covers the country on each side to a large extent. The area of waterway afforded by the bridge is 40,000 square feet, and assuming that the velocity of the water is 5½ feet per second, the discharge would amount to 2,20,000 cubic feet, equivalent to a rainfall of 1·63 inches per 24 hours over the entire district.

The work was begun in March 1875, and finished in March 1879, at a total cost of Rs. 4,50,000. Of this sum two lakhs were contributions by Native States, the balance being paid by the British Government. The bridge is built entirely of stone masonry, and consists of 11 arches of 70 feet span, on piers 56 to 60 feet in height, the total height from river bed to roadway being 82 feet. The foundations are all on the rock which extends right across the channel, though covered in places with sand.

In the design two abutment piers Nos. 4 and 7 are provided. The width of the ordinary piers is 9 feet at top, increased by one foot offsets to 15 feet above foundations. In order to save masonry, the usual cut-waters on the down-stream side are reduced to the form of a flat buttress having a batter of 1 in 7.

In the superstructure the only peculiarity is the introduction of concrete spandrel arches. Two of these of 7½ feet span, supported on a centre wall, and on the two face walls, suffice to carry the roadway over the piers between the main arches. By this means two voids or spaces are left over each pier, measuring 30′ × 10′ × 7½′, equal to 4,500 cubic feet. If these had been filled up in the usual way with gravel or stone, it would have added 250 tons to the weight over the pier. As it is the weight of an arch and its superstructure amounts to 1,200 tons, and this is carried on a pier measuring 9′ × 22′ = 198 square feet, producing a pressure of upwards of 6 tons, or 12,450 lbs. per square foot. The additional 250 tons would increase the pressure to 16,400 lbs., or 114 lbs. per square inch, which would be an extreme weight for ordinary masonry.

The omission of wing walls from the design will also be noted. If the usual pattern of splayed wings, 82 feet high from the rock, had been built it would have added another lakh of rupees to the estimate. The mass of loose stone extending round the abutments answers the same purpose at far less cost, and without seriously obstructing the waterway, as the end arches are beyond the natural bank of the river. There is another objection to masonry wings bonded to the abutment, for either from unequal settlement or other cause they are often found to separate from the abutment, leaving an unsightly crack at the shoulder, if not actually endangering the whole structure.

With regard to the materials available for the work, the stone was quarried from some hills 2½ miles from the site, and consisted of the ordinary dark coloured trap of the district. It is a hard and durable stone, weighing 185 lbs. to the foot, but intractable to work from the want of any regular planes of cleavage. The stone was brought to the bridge by a tramway of 2 feet 6 inches gauge, on which the trucks, each carrying about two tons of stone, were pushed by a couple of men. The line was continued down into the river bed by means of an inclined plane supplied with a drum and brake and endless chain. By this means the loaded trucks in descending pulled up the empty ones for the return trip.

The kankar for lime was collected in the neighbourhood: a part consisted of the nodular kind found in the soil, and part of the quarried or block kankar. It was burnt with charcoal in continuous kilns similar to Mr. Dejoux's pattern, but higher and narrower, *viz.*, 18 feet from hearth to top, 5 feet diameter at top, and 3 feet at bottom, and they were built under the river bank for convenience of loading from above, without the necessity of climbing steps. These tall kilns require less fuel and burn the lime more steadily, being less liable to the influence of draughts from change of wind, &c. The quantity of charcoal allowed was 40 cubic feet, or 800 lbs. to the 100 cubic feet of kankar. For the more important portions of the work, *viz.*, the foundations, arching, and the concrete spandrel arches, the kankar was treated as a cement in being hot ground, (*i. e.* without slaking,) and then sifted through a fine screen of eight meshes to the linear inch. This plan gives a quicker setting and stronger mortar than that obtained by slaking first and then mixing; provided the kankar is clean, hard, and of hydraulic nature. The average tensile strength of briquettes made of the bridge mortar ($1\frac{1}{2}$ sand to 1 of lime) was 50 lbs. per square inch at the age of one month, increasing to 65 at two months, and continuing to increase up to a year. The mortar made from the cement or hot ground lime usually gave results better by 20 per cent. than the above.

In excavating the foundations, the water was kept out by bunds of clay round the site; the rock was usually excavated to a depth of 5 feet or until a solid stratum was reached. The first two courses of masonry were built of solid block in course set in Portland cement, the stones being chisel-dressed on beds, and measuring not less than 2′ 6″ × 18″ × 12″. Above this, and above ground up to springing level, the masonry of piers and abutment is constructed of a mixture of block in course and rubble as follows:—

The facing to a width of 18 inches is block in course. These are large stones 10 to 14 inches in depth, 2 to 4 feet 6 inches in length, and 18 inches wide, with top and bottom beds chisel-dressed throughout, so as to allow of ½-inch bed joints, with no pitch holes of more than 6 inches diameter, and 1½ inch depth. The side joints are vertical, but excepting for 12 inches in from the face are only hammer-squared, so as to give joints of 2 to 3 inches width. In addition to the face stones, bands of this block in course 18 inches in width are run transversely and longitudinally about 5 feet apart in a chess board or gridiron pattern over the whole area of the structure. These courses lie one over the other from bottom to top, thus leaving rectangular spaces or pockets between. These spaces are filled in simultaneously with coursed rubble consisting of roughly squared stone about 1 foot in depth, and measuring not less than $1\frac{1}{2}$ cubic feet; the stones being carefully fitted give joints of 4 to 8 inches, and all hollows are filled with smaller stones completely embedded in mortar.

The estimate rate for this class of masonry was Rs. 60 per 100 cubic feet, and it was nearly worked up to as follows:—

Material.

	RS. AS. P.	RS. AS. P.
50 cubic feet dressed stone, @ $6\frac{1}{2}$ annas per cubic foot, ...	20 5 0	
60 cubic feet rubble, @ Rs. 12 per 100 cubic feet, ..	7 3 2	
Carriage of 110 cubic feet stone $2\frac{1}{2}$ miles, @ 9 pie per foot, ...	5 2 6	
Mortar, ...	6 0 0	
Total material, Rs., ...		38 10 8

Labour.

	RS. AS. P.	RS. AS. P.
12 Masons for setting, @ 10 annas each, ...	7 8 0	
20 Navaghannies or bamboo coolies, @ 4 annas, ..	5 0 0	
Coolies, women and boys, ...	2 0 0	
Smiths, steel and charcoal, ...	2 8 0	
Scaffolding, ...	1 8 0	
Sundries, ...	1 8 0	
Total labour, Rs.		20 0 0
Total per 100 cubic feet, Rs.		58 10 8

Up to 30 feet from the ground, the material was carried up to the piers over inclined planes of planks supported on scaffolding; and in the case of the abutment piers, which required a double quantity of stone, this was continued in a spiral form round the pier up to the top. But for the ordinary piers a kind of revolving derrick, set up on the pier, was found to answer well. The hoisting chain and revolving arrangements were worked entirely from below, so as not to take up the working space on the pier. The top of the pier under springers was finished off with two courses of solid block in course.

In designing the centres, it appeared to be the most economical plan to dispense with intermediate supports, and to make the ribs strong enough to span from pier to pier as a girder. Supposing two rows of intermediate posts or pillars had been introduced to carry the weight from the ground, each post must have been from 60 to 70 feet high, and to sustain the weight (upwards of 20 tons each) they could not be less than 15 inches square, also they would require support against cross-breaking by a strong system of transverse struts. All this would require a quantity of the largest and therefore most expensive class of timber.

The total weight of the plain arch ring 3 feet 6 inches to 3 feet thick is 520 tons, and the portion of this actually bearing on the centre (calculated by the formula given by Rankine at page 488, Rankine's Civil Engineering) is 300 tons. The plan adopted is a system of four ribs resting on brackets supported on off-sets left in the piers. A rib consists, *vide* figure, of an arched or polygonal frame of timber following the shape of the arch in combination with a system of raking struts and a tie-beam. The arch frame consists of double back pieces of 10″ × 4″ planks set on edge and spaced 8 inches apart, by means of packing pieces 2′ 6″ × 10″ × 8″ inserted between them. The ends of the back pieces are cut radially so as to butt fairly one against the other, the joint being completed by $\frac{5}{8}$-inch bolts and one inch bamboo pins through the packing pieces. In the centre or crown of the rib, the 8-inch space is filled by a straining beam 15′ × 12″ × 8″ to receive the heads of the two large struts 18′ × 12″ × 8″. On both sides of the straining beam, for a distance of 8 feet, the 8-inch space is also filled with two additional 10″ × 4″ back pieces, forming the caps to the two smaller struts 14′ × 10″ × 8″. There are also two vertical struts 8′ × 5″ × 5″ to stay out the rib above end of each bracket. The feet of all three struts on either side are stepped into a horizontal plate 12″ × 8″ resting on the striking wedges. The straining beam is trussed in centre by a 8″ × 8″ vertical post suspended on $1\frac{1}{2}$-inch round truss rods. The tie-beam is of double 10″ × 4″ planks, so as to encircle the raking struts, it also secures the centre truss post by means of the 2-inch iron pin which is passed through the eyes of the truss rods and centre of tie-beam. To the same pin are also attached the two counter-ties of $\frac{5}{8}$-inch chain, whose lower ends are attached to the end of the horizontal plates. These latter chains are merely intended to hold the rib together while hoisting into position.

The scantlings of the bracket are given in *Plate* I., on the inside of the right angle is bolted a large 5″ × 1″ iron angle plate, and through a hole in this plate is passed the 2-inch iron masonry tie-bolt which holds up the bracket against the pier. The rear end of the bracket at top is formed into a step inclined in direction of radius by a chock piece bolted on it. The end of the back piece projecting beyond the horizontal plate is also cut off radially, so as to abut fairly on a set of wedges resting on this step, thus counteracting any tendency of the bracket to fall outwards from the weight at its outer end.

The timber used in the centres was chiefly muttee (eyne) and nana (ben teak). These are very strong but heavy woods, weighing from 55 to 62 pounds per foot. The weight of a bracket was $1\frac{1}{2}$ tons, and that of a rib complete $4\frac{3}{4}$ tons.

The hoisting was done in this way. The four 2-inch tie-bolts having been inserted through the holes left for the purpose in the masonry, the eight brackets were hoisted in succession by means of a small derrick fixed on the pier with a double $\frac{1}{2}$-inch chain fall worked from a winch below. Between the feet of the brackets and the step cut in the pier, wooden packing pieces were placed, so as to take all the weight of the brackets off the tie-rods. Then the top of the brackets having been covered with 3-inch planks, formed a convenient platform for the next operation of hoisting the ribs. These were brought in pieces on to the river bed below, and there put together alongside one another, in a position oblique to the bridge axis, so as to clear the pier offsets. The hoisting was done with an ordinary jib crane made of two teak spars, the jib being 37 feet long and about 11 inches mean diameter, and the crane post 24 feet long and 9 inches diameter. The back and front suspension stays consisted of treble $\frac{5}{8}$-inch chains. The rear ends of the back stays being separated were made fast to the two outer ribs of the centre of the arch in rear near their crowns; the crane itself being set up on the outer end of the two centre brackets on two 15-inch square balks. The jib at an angle of 45° had a rake of 24 feet, and thus could command the centre of the span 35 feet from pier. The hoisting tackle consisted of a treble fall of $\frac{5}{8}$-inch chain working through two double pulley blocks with 10-inch sheaves. The hoisting end of the chain was led down direct from the fixed block at end of jib, to a large double purchase winch secured to the bracket platform immediately in rear of the crane. The hook of the lower or running block having been made fast to the back piece of rib at its centre, it was first set upright on the ground to tighten up bolts and to drive the wooden tree-nails on the underside. Then the hoisting was continued, the rib hanging vertically, but with its plane athwart the line of bridge, until it was high enough to clear the pier offsets, when it was swung by guy-ropes under the brackets, and passed up still in an oblique position through the outer bracket openings up to its final height about 2 feet above. It was then brought parallel to its proper position, and lowered on to balks placed to receive it. The ribs destined for the outer positions still required moving side ways into position, and this proved a somewhat hazardous operation, because the hoisting tackle which kept it upright had to be removed, and its office supplied by guy-ropes led down to winches placed on the ground some 200 feet up and down-stream. The guys were made of ½-inch wire-rope, two on each side; 4-inch Manilla rope was first tried, but did not answer on account of its tendency to stretch when a gust of wind acting on a large surface of the rib threw a sudden strain on it. Traversing the feet of the ribs side ways was effected by differential pulley blocks fastened to the horizontal plates on each side, the other ends being fixed to the outer brackets, and the traversing ways being slightly greased. No sooner was a pair of ribs fairly in position, than they were secured together by nailing on some of the 3-inch laggings, and fixing diagonal bracing in centre between the truss posts. The laggings consisted of deal planks, and were fastened with bamboo pins instead of nails, in order to facilitate removal and cause less damage to the planks.

The stones for arching are all cut stone, *i.e.*, dressed fair on all sides, and all one foot thick at soffit. The 3 feet 6 inches thickness near springing is made up by a course of 2 feet soffit stones, and 1 foot 6 inches back stones, alternating with a course of 1 foot 6 inches soffit and 2 feet back. Nearer the crown the stones run 1 foot 9 inches and 1 foot 3 inches alternatively; the average breadth being 2 feet. They were all hoisted from below, through holes left for the purpose in the laggings, by means of the small triangular derrick frames, with an iron block and chain fall overhanging the hole. The other end of the chain having been passed through a leading block on the ground level, was attached to a team of four or six bullocks, who thus drew up the load just as they would draw a mote from a well. Before the masonry reached the tie-beam, or at about 8 feet from springing, the crown of the centre had to be loaded with about 20 tons of stone, *i.e.*, 5 tons to each rib, to counteract a tendency the ribs gave to rise at the crown. This did not prevent a slight crack opening later on in the haunches, but not sufficient to cause any uneasiness. The last 18 feet of the ring on each side of the crown was carried up and keyed in with soffit stones before completing with back stones to the full thickness, in order to lighten the weight on the centres as much as possible. The backing was carried up to a height of 8 feet only above springing, and finished off level. Where there was no cause for delay, it took from three weeks to a month to turn an arch.

Striking the centres was usually effected the second day after keying in the outer ring. The settlement at the crown as taken by a level was generally less than half an inch. When the striking wedges had been properly greased before putting in with a mixture of soap and grease, they gave little trouble in getting out, but in one or two cases where this had not been done, the wood had to be cut away with chisels. The sand boxes were chiefly used to lower the centre after it was clear of the arch, and for this they are well adapted, but for supporting the work under construction they are not so reliable as hard wood wedges, because there is always the chance of settlement from careless packing.

In the working season of 1876-77 the first four arches were turned, and in the following season the remaining seven. For the rains of 1877 the ribs were left suspended by chains under the arch rings, the laggings and the brackets having been taken down. Lowering the ribs was done through holes left for the purpose in the keystone course of the arch ring. The winch having been placed with its barrel over the hole with the lowering chain coiled on it, the operation was done just in the inverse way to hoisting.

With regard to the investigation of the strains in the rib, it is evident that where two systems of arch and truss are connected in one frame, it is impossible to determine the exact proportion of weight upon each. In fact, were it not for the yielding of the joints of the rib, all this sub-structure of trussing would be unstrained. Supposing, however, that the arched frame bears the whole load; we have, according to Rankine, equation 7, page 488, Rankine's Civil Engineering, the horizontal stress at middle section, or $H = M \div d$, where

$$M = W$$

which worked out gives in this case M = 1146 foot tons, and $H = \frac{1146}{17}$

= 65 tons. The section of the double 10″ × 4″ back piece averages about 70 square inches. This gives a pressure of about 2,000 lbs. to the inch, a strain exceeding the ordinary safe working load, but not in excess of the crushing strength of hard wood. It may be shown also that the secondary system of radiating struts supported on end of bracket is quite capable of itself of sustaining the whole load. Experience proved pretty conclusively, however, that the arch bore the main portion in every case, for it was invariably found that, on easing the centres, the back wedges supporting the arch were jammed harder than the front ones carrying the struts. Indeed the latter were sometimes eased clear of the plate above at the first blow of the hammer, and before the back wedges had been struck at all, showing that the weight of the arch was then taken by the back piece only. And this was the case to the last, although owing to the fact that five centres only were made for turning eleven arches, some ribs were used three times over, and the consequent hoisting, lowering and shifting with an occasional immersion in the river naturally entailed much rough usage to the joints.

The head walls and a centre wall are carried up to a height of 10 feet above backing, to carry the concrete spandrel arches. These were laid on a wooden centering, composed of planks supported on small ribs of 7½ feet span. The rise of the arch is 1 foot, thickness at crown 15 inches, at sides 2 feet, and 2 feet 6 inches over centre wall. Drainage holes are left at the sides, so as to lead the water from the roadway on the backing, and thence through the arch ring by holes made through it.

The concrete was composed of 1 part hot ground kankar lime, 1 of sand, 4 of broken stone. The latter was made from a soft species of porous trap found in the river bed, and it was broken small enough to pass through a 1½-inch ring. The mixing was done by hand as follows:—The stone having been wetted was spread out on a wooden floor to a depth of 4 inches, then the sand and unslaked lime over it in the proper proportions. The whole was then turned over, first dry and then with water, and sent on to the work while still warm from the heat of slaking. The concrete was laid over the arch in layers of about 6 inches thickness, which would be reduced to about 4 inches by ramming. At 4 feet intervals across the arches, and enclosed in the concrete, are bars of 2½″ × ½″ iron laid edgewise on the centres, and long enough to reach across the bridge. The work was kept wet for a month, when the centerings were usually lowered, and the sides of the openings walled up with dry stone. These arches have since been tested by hauling over them a cart loaded with rails so as to weigh nearly two tons. Although some of the arches tested were only a month old, this weight had no appreciable effect on them. The concrete, however, would have been better with a larger proportion of lime, say 1 to 3 of other material. Its cost, including centering, but exclusive of the bar iron, amounted to Rs. 18 per 100 cubic feet.

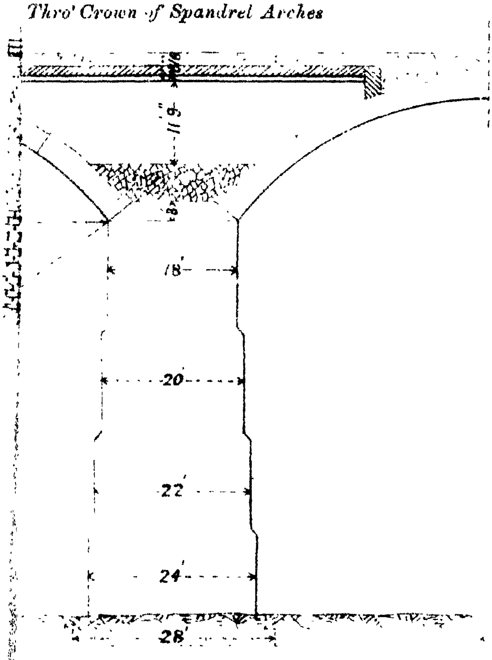
There were two accidents to life during the course of the work, neither of which could be ascribed to any failure in the working. One man fell to the ground from the centres, the other was struck when on the ground below the arching by a small wooden handspike let fall by a mason working above.

The chief items in the Work Abstract as actually carried out are—

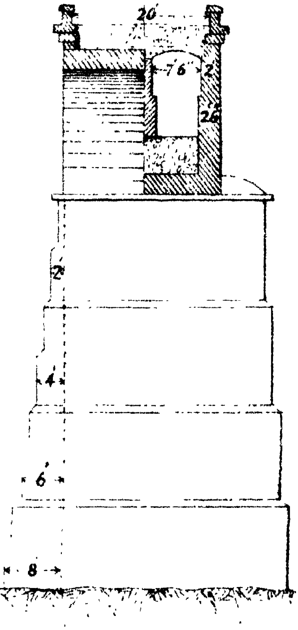
c. ft.		Rs.
6,03,000	Excavating foundations in earth, at Rs. 1-2-3 per 100 cubic feet, ...	6,900
49,000	Excavation in rock and water, at Rs. 10-13-10 per 100 cubic feet, ...	5,366
54,250	Block in course in foundations, at Rs. 68-7-7 per 100 cubic feet, ...	37,145
3,19,800	Block in course and rubble superstructure of piers and abutments, at Rs. 59-12-3 per 100 cubic feet, ..	1,91,025
69,582	Arching in dressed stone, at Rs. 87-8-4 per 100 cubic feet,	60,897
52,500	Coursed rubble in head walls, at Rs. 24-10-2 per 100 cubic feet, ...	12,946
17,480	Concrete in spandrel arches, at Rs. 18-9-9 per 100 cubic feet, ...	3,251
rg. ft. 1,816	Cornice, at Rs. 3-1-8 per foot, ...	5,635
1,816	Parapet, at Rs. 5-2-8 per running foot, ...	9,480
No. 5	Centres, at Rs. 750 each, ...	3,750
6	Removals and resetting up at Rs. 1,025, ...	6,150
	Earthen approaches, including stone endings, ..	16,044
	Minor items and contingencies, ...	59,644
		4,18,233

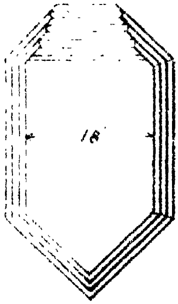
E. D'O. T.

LONGITUDINAL SECTION
Thro' Crown of Spandrel Arches



CROSS SECTION
Thro' Crown over Pier





No. CCCXV.

REPORT ON THE PROPOSED WATER SUPPLY TO THE TOWN OF SHOLAPUR.

[*Vide* Plate].

By C. T. Burke, Esq., *B.E.*, *Assoc. Inst. C.E.*

The town of Sholapur, the sudder station of the Sholapur district, is situated in latitude 17° 40′ north, and longitude 76° 57′ east, its distance from the sea in a direct line is about 184 miles, and its height above mean sea level at the site of service reservoir No. 2 is 1,563 feet.

The mean average rainfall in the past eleven years amounted to 31·99 inches; the maximum and minimum in the same period being in 1878 and 1876 respectively 69·37 and 10·57 inches.

Previous to the construction of the Ekruk tank and canals, the inhabitants of this large and populous town were dependent upon the uncertain supply obtained from wells for water for drinking and domestic purposes, and were it not for the supply afforded by the Ekruk tank in 1876, it is not too much to say, that a population of more than 50,000 would have experienced the dire effects of a water famine.

The principal canal leading from the Ekruk tank passes around the town of Sholapur, at distances varying from half to one mile from the outskirts, and as much as two or three miles from the interior parts of the town, the supply though constant, and abundant, is at long distances from the bulk of the inhabitants; it has, therefore, been decided by the Municipality to undertake a scheme for a complete supply of drinking water to the town and its environs.

In this scheme it is proposed to draw off the water from the Ekruk perennial canal, in the 4th mile, through a 9-inch iron pipe into a settling tank, from which it is to be led into the pump well situated in the engine house, and from thence is to be pumped direct, through a line of pipes, 9 inches in diameter, into two service reservoirs placed at different levels in the town, and from which the distribution will be effected.

The calculations of the engine power will be found in Appendix No. I., from which it will be seen that about 40 horse-power will be required to raise the requisite supply in ten hours. It is proposed to use two special pumps by Tangye Brothers and Holman, each of 20 horse-power, and so arranged, that either can be worked separately in the case of accident to the other, or combined, so as to give out the full effect required.

The calculations upon which the dimensions given to the main pipes are based will be found in Appendix No. I.

Appendix No. II. contains detailed descriptions of the various parts of the works, which are illustrated in the *Plate*.

The total estimated cost of the works including establishment and all charges is Rs. 1,93,894, distributed as per abstract estimate, *see* Appendix No. II. The cost per head of population to be supplied will be Rs. 3·827.

The following may be assumed as a fair estimate of the monthly expenses necessary in connection with the engines, &c. :—

	Rs.
Engineer with 1st Class certificate, ...	75
Fireman, ...	25
Coal per 10 hours, or 19 cwt., @ Rs. 36 per ton, ...	1,026
Oil and waste, ...	6
Sundry stores, ...	3
Monthly expenditure Rs., ...	1,135

If wood fuel be used, about $2\frac{1}{2}$ tons will be required per day, and assuming a rate of Rs. 8 per ton, the monthly cost of fuel will be Rs. 600, and the other items remaining the same, the monthly expenses will be reduced to Rs. 709. This estimate is of course exclusive of depreciation of machinery, and the ordinary expenses attending the maintenance of the works. It may be here remarked that the depreciation of machinery is greater in the case where wood fuel is used, as it is more destructive to iron than coals.

The maximum cost of coals in Bombay, distributed over the past ten years, gives a mean average of Rs. 21·64, to which must be added the cost of carriage by rail and road, which brings the average up to Rs. 36 per ton delivered on the works.

The following is the result of an analysis of samples of water taken from the canal at the place from whence it is proposed to take the supply:—

Total solids, grains per gallon, ...	10·85
Chlorine, ...	0·46
Free ammonia, parts per million, ...	0·08
Albuminoid ammonia, ...	0·15
Sediments. Vegetable débris and diatoms.	

It is satisfactory to know that the water is sufficiently pure to admit of its use for all domestic purposes without the intervention of filtration.

APPENDIX No. I.

Calculations of the power of machinery, dimensions of pipes, &c., required.

Population of Sholapur as per return corrected to 1872, ...	...	50,666
Allowance per head per diem, ...	=	5 gallons.
Quantity of water to be delivered in the town daily,	...	2,53,330

Relative levels of important parts of the proposed work—

Surface of water in Ekruk perennial canal at "take off,"	=	163·50
'Full supply' or surface level of water in settling reservoir when full, ...	=	163·00
Floor level of ditto, ...	=	153·00
Bottom of engine well, ...	=	150·00
Sill of main pipe at starting point, ...	=	153·00
'Full supply' level of surface of water in service reservoir when full, ...	=	252·00
Floor level of ditto, ...	=	239·00

The reduced levels of important parts of the town to be commanded will be found on the plan in *Plate*.

The total length of main pipe, ... = 8,470 feet.

Actual height to which water must be raised, = 99 „

Discharge in cubic feet per second $= \dfrac{\text{D in gallons}}{6{\cdot}25 \times 10 \times 60 \times 60}$

$$= \frac{253{\cdot}330}{6{\cdot}25 \times 10 \times 60 \times 60}$$

$= 1{\cdot}125$ cubic feet per second.

Let d = diameter of pipe in feet.

V = Velocity in feet per second.

h = Head or fall per mile in feet.

D = Discharge in cubic feet per second.

D = 1·12, assumed = 8 inches or ·66 foot.

$$\therefore V = \frac{D}{[illegible]}$$

= 3·28 feet per second.

$$h_f = \frac{[illegible]}{d} = \frac{[illegible]}{0{\cdot}66},$$

where h_f = head due to friction per mile

= 37·49 feet per mile.

∴ Head due to friction in total length of pipe $= \dfrac{8470 \times 37{\cdot}49}{2580}$

= 60 feet nearly.

In the above calculations, the diameter of the main pipe was assumed to be 8 inches, while it is really to be 9 inches, the extra inch being allowed for deposits, incrustation, &c.

Absolute power of engine required.—It is proposed to raise the whole day's supply, 2,53,330 gallons, in 10 hours. Work to be done by the pumps in raising 2,53,330 gallons to a height of 159 feet in 10 hours,

horse-power $= \dfrac{253330 \times 159 \times \frac{24}{10}}{47{,}52{,}000}$ horse-power = 20·34.

To which add 90 per cent. additional power to provide against contingencies, that is assuming the efficiency of the pumps to be = 0·526, the absolute horse-power required = 38·70.

It is proposed to use two engines of 20 horse-power each, which can be worked separately or combined.

APPENDIX No. II.

Estimate of the probable cost of supplying with water the town of Sholapur, situated in the Taluka and District of Sholapur. Amount of Estimate Rs. 1,93,894.

Description.—The water to be taken from the Ekruk perennial canal in the 4th mile, and passed by an iron pipe into a settling tank, designed to hold $5\frac{1}{3}$ days' supply. From this tank the water to be led off to the pump well, situated in the engine house, and from thence to be pumped up and conducted through the main pipe to service reservoirs Nos. 1 and 2.

The service reservoirs contain a combined supply of $3\frac{2}{3}$ days, and from them the distribution in the Town, Sudder Bazaar, and Modi-khana will be effected.

The *Plate* illustrates the different works.

Fig. 1. A general plan showing position of the settling tank, engine house, main pipes, service reservoirs and proposed lines of distributing pipes.

Fig. 2. Details of settling tanks.

Fig. 3. Details of service reservoir No. 2.

Steam pumps, boilers, engine house, &c.—The pumping machinery to consist of two special steam pumps, by Tangye Brothers and Holman, each of 20 horse-power, and provided with connections, so that one or both can be worked as occasion may require. Each pump to have a 16-inch steam cylinder, and 10-inch double-acting water cylinder, both having 36-inch stroke.

Two boilers to be provided, each 18 feet in length and 5 feet diameter, of the Cornish type, with a flue 32 inches diameter; they shall be fitted with steam domes 28 inches diameter and 30 inches high, and be complete with all fittings; steam pipes to connect the boiler and pump together with exhaust steam pipes to be provided.

A building of suitable dimensions and design to be provided as engine and boiler house.

A coal or fuel shed and small bungalow for the Engine Driver's residence to be constructed in the engine house compound.

Settling tank.—The water to be led by a 9-inch pipe, fitted with a sluice valve, from the Ekruk perennial canal, into a settling tank, of which side section is shown in *Fig.* 2.

This tank is to have a clear length of 147·66 feet, and width of 147·66 feet at the full supply level, and 146 feet at the bottom, with a depth of 10 feet. Its available capacity = 13,50,562 gallons, or 5⅓ days' supply.

The nature of the material at the site of the reservoir, and through which it will be necessary to excavate, consists of muram, soft and hard, with boulders and soft rock.

A lining of rubble masonry, with a parapet 3 feet in height, to be constructed of the dimensions shown in the figure.

A 9-inch scouring pipe fitted with valve to be placed at the bottom on the western side, communicating with the nullah, to admit of the reservoir being cleared out when necessary.

A supply pipe to be fixed leading from the tank to the pump well.

Main pipes.—The main pipe to be laid in one continuous line, extending from the engine or pump house to the Tuljapur gateway, thence along the main street through the Bijapur gateway and service reservoir No. 2, *see Fig.* 1.

The pipes to have a clear diameter of 9 inches; the joints to be turned and bored of the pattern shown in *Fig.* 1.

Service Reservoir No. 2.—The site selected is situated in Survey No. 212, close to the Collector's compound.

The contents = 6,00,422 gallons, or 2⅓ days' supply.

The reservoir to be circular in shape on plan, 98 feet 6 inches mean diameter.

For general design and dimensions *see Fig.* 3.

The nature of the material on which the building is to be constructed consists of muram and rock of various degrees of hardness mixed with boulders; it will be necessary, owing to the porous nature of the soil, to lay concrete all over the floor of a total thickness of 12 inches.

The foundations of the walls to be excavated to R. L. 236·00, and filled in with concrete for a height of 5 feet; on this foundation the main walls to be constructed of the dimensions and section shown on the plan. This superstructure to be of the best rubble masonry, coped with an ashlar cornice, as shown.

The radiating and intermediate wall to have arches as shown, and to be of the design and several dimensions shown in *Fig.* 3.

The roof to consist of plain galvanized iron sheets laid on the walls and on intermediate T and L iron bars.

The floor to be plastered with Portland cement, and the exterior walls to be pointed on the outside.

A scouring valve to be fixed in a convenient place to admit of the reservoir being emptied and cleared out when necessary.

Service Reservoir No. 1.—To be similar in design and construction to No. 2, but of smaller dimensions, and capable of containing 1⅓ days' supply only.

Stand-post and Platform Specification.—The stand-posts and platforms to be of the general design, &c.

Abstract Estimate of cost.

Items.	Amount.		
	RS.	AS.	P.
Steam pumps, engine house, &c., as per abstract, ...	27,300	0	0
Settling tank, ...	15,158	0	0
Main pipes, ...	46,081	0	0
Service reservoir No. 1, ...	9,648	0	0
„ „ „ 2, ...	15,537	0	0
Distributing pipes, &c., ...	46,807	0	0
Stand-posts and platforms, ...	5,190	0	0
Rupees, ..	1,65,721	0	0
Public Works Establishment, at 15 °/o, ...	24,858	2	4
Tools and Plant, at 2 °/o, ...	3,314	6	8
Total Rupees, ..	1,93,894	0	0

C. T. B.

No. CCCXVI.

NOTES ON THE FLOODS OF THE SUTLEJ AND EAST AND WEST BEYN NALLAHS ON THE SCINDE, PUNJAB AND DELHI RAILWAY, AND ON THE INDUS ON THE INDUS VALLEY STATE RAILWAY.

[*Vide* Plate.]

Report by C. STONE, ESQ., *Acting Agent and Chief Engineer, Scinde, Punjab and Delhi Railway, on proposed utilization of eight spans Sutlej Bridge girders. September* 1878.

I HAVE the honor to invite the attention of the Government of India to a proposal to remove eight spans of girders from the Ludhiana or east end of the above bridge.

It will be in the recollection of the Consulting Engineer to Government of the Scinde, Punjab and Delhi Railway, both past and present, of my opinion (often expressed) that the bridge was too long, causing from such excessive length the wandering of the main channels, the accumulation of large sand banks, that consequently contracted the channels, and which, there is little doubt, caused the destruction of the brick well piers 48 and 49 in August 1876.

The scour of the main channels between these piers was 62 feet. The fallen girders and piers and the stone protection thrown in from time to time rendered it quite impossible to sink new piers between 47 and 50.

I then proposed filling up the deep channel with stone and block kankar, sinking a boat caisson filled with stone on the exact site of the old well pier and over the caisson (after ramming the stone and kankar with a heavy pile driver), erecting what I term a cluster column pier, composed of four cast-iron cylinders, fixed to a large wrought-iron bed plate strengthened

Note.—Many letters, plans, &c., in the correspondence are omitted. Only the leading ones have been selected.—[ED.]

with iron rolled joists. The drawing in detail with full description was duly submitted to Government through the Consulting Engineer, sanctioned at once; the columns were erected, and the bridge re-opened for traffic on the 12th December 1876.

The three spans of girder required to replace the lost three spans were removed from the eastern end of the bridge, taken bodily down to the gap and erected on the cluster column pier, and in lieu of the three girders so removed from the east abutment, a flood bank of earthwork faced with stone was thrown up down to span or pier 56.

The cluster column piers have now stood two floods, at first there was a little settlement and transverse movement as I fully expected, but for the past six months they have not moved in the slightest degree.

In my annual inspection report, dated the 20th of March 1878, page 3, I again referred to my belief that the bridge was too long, and that it was my intention at the end of the year to re-open this question with a view of showing that the bridge, if necessary, might be shortened by eight spans. The recent disasters in the Beas and East Beyn Valleys have hastened the submission of these views, and I now wish to lay before the Government of India a proposal for their careful consideration, and, if approved, to solicit sanction for the removal of the eight spans with the object of utilizing them for works in the Beas or East Beyn Valley. I submit two tracings of the eastern end of the bridge training and protective works. Tracing No. 1 shows the cluster column pier and stone work and caissons upon which they were founded, and tracing No. 2 a plan of the training works, old and new.

After the erection of the cluster column pier, the long groyne 1876-77 was carried out to protect the eastern end of the bridge, the effect of this groyne has been to force the main channels towards the centre of the bridge, and the large island has been reduced as shown upon survey forwarded with my half-yearly inspection report to the 30th June, dated 31st July 1878. The large bay between the groyne 1876-77, and the old bank of the river 1871, has silted up, and the eastern end of the bridge may now, I am of opinion, be considered so well protected that eight more spans may be removed without risk; in fact, they are practically no longer flood openings; and even assuming that the main channel took a set eastwards and attacked the large upper bund and came down against the flood bank, we should lose earthwork instead of girder.

The plan that I now propose is to connect the end of the 1876-77 groyne with cluster column pier 48, construct it of stone, or heavy block kankar well above the highest known flood, with a good margin for settlement, and carried into the river at a very flat slope, carrying it well below the bridge and out to brick well pier No. 47; in fact, so protect the cluster column pier 48 as to make it the east abutment of the bridge, and backward from this so-called east abutment make a flood bank to connect it with the present flood bank of 1876-77, which now terminates at pier 56, and entirely remove cluster column pier 49 and the eight back spans.

The early consideration of this subject is of the greatest importance, as upon it depends what girders I shall have to send for to England on account of the re-construction of destroyed works in the Beas and Beyn Valleys, and further, that should it be approved, that I may without delay make the necessary arrangement for the removal of the girder, so as not to check in any way the traffic of the line, whilst the girders are being dismantled.

By this mail I forward a copy of this letter and duplicate tracings for the consideration of the Chairman, Board of Directors, and their Consulting Engineer, and have requested them to telegraph their approval or otherwise, pending also the views of the Government of India.

Dated 22nd October 1878.

Telegram from—*Works, Railway, Simla.*

To—*Consulting Engineer, Guaranteed Railways, Lahore.*

Sutlej Bridge girders not to be moved pending report of Colonel Forbes, who has received instructions to enquire into the best means of preventing disasters similar to those of this year.

Note on the Waterway of the Sutlej Bridge at Phillour. By MAJOR J. G. FORBES, R.E.

Dated Jullundur, 19th December 1878.

The original bridge constructed over the River Sutlej in 1867 was 4,227 feet between abutments, with 37 piers of 12·5 feet diameter, thus allowing a clear waterway of 3,764 feet.

This length was fixed, not on any measured discharge or any calculation, but solely because it was observed that at Kariánah, a village about six miles above Phillour, the whole flood of the river passed between banks about 4,000 feet apart.

In 1869, in spite of efforts which had been made to train the river (*see* page 340), it changed its course, and, abandoning the bridge, turned behind the left (Ludhiána) abutment. It was then determined to add 20 spans to the 38 already existing, and the bridge thus lengthened was completed in October 1870.

In July 1872 two of the piers, Nos. 16 and 17, were carried away, and to repair the breach the gap of three spans was divided into four openings of 83 feet each. By these alterations the bridge then consisted of 59 spans and 5,730 feet clear opening. Of these spans, however, the nine on the east or Ludhiána bank were earthed up above flood level and revetted with stone, so that they were quite useless as waterway.

In August 1876, piers Nos. 48 and 49 were destroyed; and as the fallen girders and piers and the stone protection, which had been thrown in from time to time, rendered it quite impossible to sink new piers between Nos. 47 and 50, the repairs were executed by filling up the deep channel with stone and block kankar, and sinking a boat caisson filled with stone on the exact site of the old well piers. On this foundation were erected two "cluster column" piers, composed of four cast-iron cylinders fixed to a large wrought-iron bed plate; and the three girders required to replace those that were lost were removed from the east end of the bridge and erected on the cluster column piers. In place of the three girders so removed, the railway embankment was extended to pier No. 56, which has thus become the end of the bridge. From this to pier No. 50 the spans are blocked up, as stated in the last paragraph. Leaving these spans out of account, the clear waterway of the bridge as now existing is 4,830 feet, and the width between abutments 5,518 feet, or upwards of a mile.

Since the construction of the railway, we have some correct data upon which to estimate the probable flood discharge of the river.

Careful observations have been made for some years in order to ascertain the flood of the Sutlej, where it issues from the hills at Rúpar, about 45 miles above Phillour. Major Home, R.E., Officiating Chief Engineer, Irrigation Department, Punjab, states the result of these observations and actual measured discharges is, that the *maximum* flood over the weir to be built for the Sirhind Canal has been taken at 225,000 cubic feet per second, which amount is known to be largely in excess of any flood that has ever yet occurred of which there is any record.

Totally distinct observations by Mr. Palmer, Superintending Engineer, Bári Doáb Circle, show that at Ferozepore, 30 *miles below the junction of the Beas* an *extraordinary* flood of the Sutlej is 270,000 cubic feet per second; but admitting the very improbable contingency of the Beas and Sutlej being both in maximum flood at the same moment when passing Ferozepore, the discharge might amount to 350,000 cubic feet per second.

Going still further down the stream, we find that at Adamwahan, 200 miles below Ferozepore, the maximum *calculated* discharge of the Sutlej is 370,000 cubic feet per second, and the clear waterway given for the Indus Valley Railway bridge is 4,200 lineal feet, or 600 feet less than the Phillour bridge, which is 280 miles higher up, and upwards of 50 miles *above* the junction of the Beas.

From these facts then it is apparent that the *maximum* discharge of the River Sutlej at Phillour may safely be taken at 250,000 cubic feet per second; and there can be little doubt that the waterway given to the bridge is largely in excess of any possible requirement, even taking into consideration that extra scour may occur harmlessly at Adamwahan, as the pier wells are sunk to 100 feet in depth instead of 40 as at Phillour.

The waterway allowed for the East Indian Railway bridge over the Soane is the same as that given to the Phillour bridge. The piers are not protected, and the wells are less than 40 feet in depth. The Soane bridge, which was built 20 years ago, has constantly passed floods of 400,000 to 500,000 cubic feet per second, and no damage has been done to it, although scouring has, no doubt, in a great measure, been prevented by the Ganges floods backing up above the bridge. But in July 1876 it passed 550,000 cubic feet per second when it was not thus protected, and no undue scouring took place, as the flood came in a direct course on to the bridge, and was spread over the whole width of the mile of waterway allowed for it.

In the case of the Phillour bridge, large sand banks have been formed, which block the waterway. These silt deposits were undoubtedly, in my opinion, primarily induced by the oblique set of the stream some distance above the bridge, and they have been greatly aggravated by the excessive waterway allowed in it. Until last year no direct measures had been taken to remove these banks by cutting a channel through, or directing the set of the river on, them; and the consequence was, that when the flood came the main force of the stream was confined to a channel of only about 900 or 1,000 feet in width, which did not approach direct on to the bridge, but, impinging sideways, caused a lateral scour, which was further aided by the stone protection thrown in, connecting the space between some of the piers, and not others. This mass of stone consequently acted as a subaqueous spur tending to push the current over to the unprotected spans. It is therefore not surprising to find that for a distance of about 300 feet the bed has twice been scoured out to a depth of 60 feet, and that on each occasion two piers of the bridge have been carried away.

In making the above comparison, the cardinal points of difference between the two bridges must be borne in mind.

The Soane bridge is on a practically straight reach of the river, and the waterway given to the bridge is *contracted*. The flood of 1876 was 748,000 cubic feet per second, of which only about two-thirds passed through the bridge, the remainder spilling over the banks and being carried off through culverts and flood openings in the railway between Arrah and Dinapore. The effect of the contraction, and of the straightness of approach of the river, is that no excessive sand deposits occur immediately above the bridge, and no training works are necessary.

The Phillour bridge is not on a straight reach of the river, and the waterway is excessive. The consequence is that immense sand banks are formed, and heavy training works are required.

With reference to the latter point, I would invite most careful attention to the accompanying map showing the changes in the river from 1848 to 1868. It will be observed that at Kariánah the high cliff juts out like a spur, and throws the stream over to the left, inducing most serious cutting near the village of Jamálpur; extensive caving of the bank takes place below, and after a considerable bend the river is again thrown off to the right in an oblique direction to the bridge. In page 338 I mentioned that efforts had been made to "train" the river, allowing the word hitherto used in papers regarding the bridge, to stand; but I believe that all the measures that have been taken have been confined to a distance of about a mile from the bridge, and ought to be looked upon as *protective* and not "training" works; and in this sense they have been entirely successful. To train the river properly, I consider it should be attacked, as at Narora, with spurs and a longitudinal embankment at least three or four miles higher up, at the point where the Kariánah promontory throws it over to the left; and that once having got it into a direct approach, it will not be sufficient to rest satisfied with a feeling of thankfulness that the river has passed safely through the bridge, and there is nothing more to do. It is absolutely necessary that the course of the deep channel should also be carefully watched for a distance of at least two miles *below* the bridge.

The objection has been made to throwing out proper spurs or groynes, that if these training works are once commenced, there is no knowing how high up the river they may have to be extended. This objection does not, I think, hold good. The cause of the oblique set of the river is the projecting bluff at Kariánah, and there is no occasion to go higher up than this point, especially as the river is here confined between banks.

It is also stated that it will be useless trying spurs on the Sutlej, as they have failed on the Indus. I am not aware of the circumstances under which the alleged failure of the spurs occurred; but in scores of other instances these works have completely answered in diverting the course of more difficult streams to deal with than the Sutlej. The Patri, Ránipur, Ratmu and Soláni torrents, on the Ganges Canal, were thus diverted; and on the Bári Doáb Canal the Chakki river (where a projecting hill, higher than the cliff at Kariánah, was cut through) was turned entirely from its original course into the Ravi, and compelled to adopt a new channel into the Beas. I might enumerate many other instances, but it will be sufficient to point to the most recent and complete success of this system of training work, as exemplified at Narora, where for a distance of four miles above the head of the Lower Ganges Canal, and for three miles below, the River Ganges has, in the course of three or four years, been altered from its oblique set into a direct approach to, and departure from, the weir.

As the above rivers have been successfully combated, I see no reason why the Sutlej should not, in the short distance between Kariánah and Phillour, be prevented from forming the dangerous bend at Jamálpur by the proper application of a few spurs and bunds, aided possibly by one or two cuts which can easily be made by the steam dredger now at site.

In the absence of recent surveys, it is impossible to speak with certainty; but there is little doubt that sooner or later some measures *must* be adopted—unless the Sutlej is again pursued across the valley by an extension of the bridge, or the construction of a new one—in order to prevent the river getting behind the present protective works, and attacking the railway between Ludhiána and the present left abutment of the bridge. It is better to adopt measures that will at once strike at the root of the evil than to wait until the stream has taken a confirmed set towards Ludhiána, when the cost of diversion will inevitably be greater and the chances of success more problematical than now.

I need only allude to the vital necessity of keeping a direct and equable section for the main stream of the river in the vicinity of the bridge (both up-stream and down-stream), as the importance of this is now fully recognized. No amount of waterway will ensure the safety of a bridge like the one at Phillour if the whole force of a flood is concentrated in a narrow deep channel. From the measures lately adopted, and from the future use of the steam dredger, I anticipate that no immediate danger on this score need be apprehended; but these measures, to be effectually useful, must be persistent, and it will not suffice to clear a channel only in the cold weather and let it run its chance during the rainy season. If a high flood fortunately comes down at the commencement of the rains, the probabilities are, that little more will be required to maintain a proper channel; but if, as more frequently occurs, smaller floods first arrive, then the main current of the river will require to be carefully watched, and much trouble and labour will be entailed in preserving the desired equability of the stream.

When, however, the rough stone protection is completed between *all* the piers, the river will possibly not require that extreme watchfulness which it now demands.

Adverting to the question of the waterway of the bridge, I would refer to my note of December 1870, on the waterway to be given to the Oudh and Rohilkhand Railway bridge at Cawnpore, as the conditions of the Ganges there and of the Sutlej at Phillour are in three main points similar—

(*a*). The discharge of the highest recorded flood at Cawnpore was 230,000 cubic feet per second, or nearly that of the assumed (ultra ?) maximum of the Sutlej at Phillour.

(*b*). The flood velocities are nearly the same, as, although the slope of the Ganges is less than that of the Sutlej, the rise of the river in one case is 14 feet, and in the other only 8·50.

(*c*). The Ganges, like the Sutlej, has a tendency to bear away from its hard unyielding right bank, and to eat into the soft alluvial deposit on the left.

In the absence of any accurate measurements at Phillour, we may therefore consider the actual facts obtained at Cawnpore, and roughly use them as auxiliary guides in determining the proper waterway for the Sutlej bridge.

The above flood, which occurred in September 1870, was measured when at its height. Surface velocities were carefully taken at every 100 feet, and the depths accurately plumbed. Of the full discharge of 230,000 cubic feet per second, 4,000 cubic feet were diverted by spill, and the remaining 226,000 cubic feet passed between banks 2,200 feet apart, the *running* current being confined to a width of 1,900 feet only, the extra 300 being slack or back water. In this 1,900 feet the average depth of the stream was 18·80 feet, but for a width of 600 feet the actual depth was 40 feet below flood level. The surface velocities varied from a *maximum* of 10 feet per second (in a width of 200 feet only) to a *minimum* of 1·25. From these data it was shown that the volume of the river was discharged through an area of 35,727 superficial feet, with a *mean* velocity of 6·33 feet per second.

After careful consideration of the whole of the circumstances, I reported that, in my opinion, the site chosen for the Cawnpore bridge was one where it was less hazardous (on account of the meandering tendency of the stream) to give a contracted than an enlarged waterway. I stated that a *clear* waterway of 2,125 feet, with an *average* depth of about 19 feet, would be sufficient to carry off the discharge of the river; that scouring would, however, extend to at least 40 feet, and possibly more on account of the obstruction of the piers, and therefore great care would have to be taken in founding them to a sufficient depth. I further added that the width and depth of scour would, of course, depend in a great measure on the set of the river; but if the stream was properly directed, there was no valid reason why an equable section should not be maintained at the railway bridge, and the scouring reduced to a minimum. My final recommendation was, that the river for a distance of six miles above (where it was confined between banks which were not overtopped in floods), and two miles below the bridge, should be carefully protected on its left bank, so as to prevent the formation of any caving bends.

The bridge as completed consists, I believe, of 2,600 or 2,700 lineal feet of waterway (of which 300 feet are available in land spans, utilized in extraordinary floods only), and the wells are sunk to a depth of 70 or 80 feet, except where they meet with a hard kankar stratum, which extends for 600 feet from the right bank at a depth of 40 feet.

In the case of the Sutlej bridge, the wells, with the exceptions mentioned in page 345, are one-half the depth of those at Cawnpore, being only 40 feet below lowest water level, which is 8·50 below the highest flood line. To ensure the safety of the bridge, the scour ought not to be allowed to extend to a greater depth than 18 feet below the flood line, and this can be accomplished if the bed is *entirely* and effectually protected with rough stone and block kankar up to the limit shown by the shaded ink line in the accompanying sketch. In the deepest part of the channel the wells will be 30 feet below the line of scour.

As on the Ganges, so here in the Sutlej, it is advisable to contract, *within safe limits*, the waterway to be allowed. The section as proposed will pass all ordinary floods up to 185,000 cubic feet per second, with a mean velocity of 5 feet a second, and floods of 205,000 cubic feet with a velocity of 5·5 feet. The entire area allowed of 41,400 superficial feet is capable of discharging 248,400 cubic feet per second, or a *maximum* flood, with a velocity of six feet only. But in this latter case it is *possible* there may be a slight afflux, not exceeding seven inches, on the piers. This, however, is not a matter of much moment, as it is very doubtful if the Sutlej ever reaches this maximum; if it does, the velocity with the afflux will be only six feet, and as the bed will have a strong stone protection, there need be no fear on this account, even allowing that the velocity in some parts may be nine feet, as it very likely may be even in ordinary floods. This afflux, if it ever exists, will, at a distance of three miles from the bridge, be three inches, and the back water will have completely died out within six miles, or before it reaches Kariánah.

The section allows of a width of 4,420 feet between abutments, with a clear lineal waterway of 3,932 feet, or 168 feet more than was given in the original bridge. For a width of 600 feet in the centre, the depth of water is 18 feet, from which it is gradually decreased on a slope of 1·2 in 100 to either side. This depth has been fixed not solely with regard to the scour in high floods, but also with reference to the practicability of getting the stone and kankar protection down to this desired depth. It will be observed that this is the depth of the bed of the cold weather channel of the river; by therefore turning this channel in the desired direction, and confining the stream to one or two spans, the river can with safety be made to scour out the bed to any necessary depth, and this extra scour might then be filled up with blocks of stone, &c. (weighing not less than 80 pounds) to 18 feet below flood line in the centre. This stone protection would not, of course, be confined merely to the line of the bridge, but would be extended as an apron for some distance both up and down-stream.

One object attained by the section is, that the shallow wells in piers Nos. 1, 3, 8, 9, 12, which extend only to 30 and 32 feet below low water level, will be effectually protected. Many modifications of the section may, of course, be made; for instance, the dotted ink line would give a superficial area of 10,000 square feet more; or, if the present line of stone filling up to pier No. 15 be taken, and again from No. 39 to No. 47, with the intermediate portion as shown, the superficial area might be nearly doubled; but if this is done, it must be recollected that the waterway will again be blocked up by the large sand banks which will inevitably form, and which have contributed in no slight degree to the disasters which have occurred to this bridge.

The shaded ink line shows what is probably the best section to which the river might eventually be brought. With the amount of superficial waterway given, and the contraction of the lineal waterway from 4,830 feet, as at present, to 3,932 feet, the formation of sand banks will be largely prevented with the least fear of an accelerated velocity and excessive scour as now takes place. When the river has been brought to this section, the seven spans on the right bank might be removed entirely, and No. 7 pier made the right abutment of the bridge. On the left bank the nine spans from pier No. 47 to the Ludhiána abutment might be removed at once. Six of these spans have never been used (*vide* page 338), and the remaining three spans over the cluster columns are merely capable of discharging 900 cubic feet per second,—a totally insignificant amount in a maximum flood when only they would be discharging.

The waterway now existing between the Phillour abutment and pier No. 47 is amply sufficient, if the large sand bank which has been allowed to accumulate between piers Nos. 10 and 40 is cleared away, as I understand it is to be this year. I would, however, most emphatically draw attention to the manner in which the stone and block kankar is thrown in for the protection of the piers, as shown by the dotted green lines on sketch. Each pier is protected for a distance of 10 feet, and for a height of 2·5 feet *above low water level* with stone filling (but in piers Nos. 14, 16, 17, 18 and 20 it is carried up to *flood level*). From this the rough mass of stone slopes down on either side, joining in the middle of some of the spans, and not in others. From pier No. 35 to pier No. 42 the stone is thus connected, and the effect must be to throw the water off on either side and cause an extra scour in the spans, where the filling is not complete. These spaces must, therefore, also be connected, but in doing this I would guard most especially against carrying up the filling too high, and thus practically converting this stone protection into a weir. If it is finished across the river at the same height as now, the waterway will be reduced to about 30,000 superficial feet, and there will be an afflux of about 2·5 feet at the bridge and deep scouring below. The effect of this afflux will extend back about 10 miles, and at Kariánah will raise the floods by six inches. It would be better to reduce, as soon as practicable, the height of this stone, especially from piers Nos. 16 to 36, as nearly as possible, to the limit shown in the proposed section.

Native reports state that more water than formerly now comes down the Budhi nallah, which runs at the foot of the high land below Ludhiána. If this is the case, the cause of it ought to be ascertained, as there may be dangerous cutting of the Sutlej some miles higher up, similar to that of the Beas near the Beyn jhils.

Summarising the conclusions arrived at in this Note, I suggest—

(i). That the river should be properly trained from Kariánah to the Phillour bridge, and that for two miles below the bridge the set of the stream should also be watched (pages 340—341).

(ii). That the formation of sand banks in the vicinity of the bridge should be prevented.

(iii). That the bridge should be curtailed in length by the immediate removal of nine spans on the left bank, and ultimately of seven spans on the right bank, when the bed has been completely protected up to the shaded ink line on section (page 345).

(iv). That extreme caution should be used in filling in the stone protection, so as to ensure the water not being raised at the bridge (page 346).

(v). That the cause of the affirmed increase of the Budhi nallah should be ascertained, and measures taken, if necessary, to prevent the Sutlej cutting into it.

Remarks by COL. J. G. MEDLEY, R.E., *on Major Forbes' Note on the Sutlej Railway Bridge at Phillour.*

Dated Lahore, 11th January 1879.

I append a printed Note of my own on the same subject which was sent by me to the Agent, Scinde, Punjab and Delhi Railway and to Government on the 26th March 1877, which Major Forbes had not previously seen, and which will show that I am quite in accord with the conclusions to which he has come as to the superfluous waterway of this bridge.

We are both in accord with the Chief Engineer, Scinde, Punjab and Delhi Railway (Mr. Stone) in considering that nine spans may be safely and advantageously taken away from the Ludhiána end (in addition to the three which were removed two years ago), and I have authorized him to act accordingly, the girders being urgently required for the new bridges in the Beyn and Beas Valleys.

With regard to the seven spans that may ultimately be removed from the Phillour end, no present action is required.

Major Forbes' third recommendation is therefore disposed of.

His second recommendation will also be acted upon, as far as possible, by the help of the steam dredger, which will be set to work as soon as the river begins to rise. Besides this, however, I believe Mr. Stone agrees in thinking that it is desirable to cut one or more channels through the sand bank (which may perhaps be kept open by the dredger); it would be as well to cut from below bridge upwards to prevent silting up.

The fourth recommendation I have brought to the Chief Engineer's notice, and requested that stone should not be piled up round the piers above the low water line, but that the stone protection may be put in down below by taking advantage of the scouring action of the stream.

My previous Note will show that I am quite in accord with Major Forbes as to the necessity of a continuous flooring right across the river between the piers; and but for the late disasters in the Beas Valley, and the very heavy work and expenditure now rendered imperative, I should have recommended the systematic prosecution of this work during the present season over the most exposed portion of the bridge. This, however, must for the present be postponed, but I will ask the Chief Engineer to complete the protection round all the piers if possible.

I will also ask the Chief Engineer for an early report on Major Forbes' first and fifth recommendations. The work thrown on the Engineering Department is just now so very heavy, that it will be impossible to undertake any fresh work, however advisable, which is not urgently necessary; but the dangers noted by Major Forbes should certainly not be lost sight of. It would seem desirable, as soon as possible, to have a survey made of the river banks up to Kariánah in continuation of the survey plan of 1868 (is there no more recent one?), so as to show how far the river has encroached on the left bank within the last 10 years.

The danger of the Kariánah (natural) spur is sufficiently obvious from an inspection of the plan; and but that this spur evidently protects so many villages below, the bridge and railway bank would evidently be much safer if this spur were cut or blasted away. If this should not be done, however, then it would seem advisable to construct a counteracting spur or spurs from any convenient spot on the opposite bank; and seeing how successful such spurs have proved at the Beas and elsewhere, I decidedly recommended that the feasibility of such a work should be examined and reported on at an early date.

Since these Notes were written, the waterway has been reduced by nine spans, to the manifest imnrovement of the uniformity of the flow during the heavy floods of the present season.

Notes on the Sutlej Railway Bridge, Phillour. By Col. J. G. Medley, R.E.

Dated Lahore, 26th March, 1877.

Having lately inspected the work in progress at Phillour in company with the Chief Engineer, Scinde, Punjab and Delhi Railway, it may be useful if I note the present state of the river and bridge at this important crossing, and give my opinion on the works now in progress for preventing further disastrous breaks.

Error of increasing the original waterway of the bridge.—Several years ago, when it was determined to add 20 spans to the original design for this bridge, I ventured the opinion that such a proceeding was wrong; that if the perpetually shifting current of the river was thus to be followed, there was no security that the whole valley from Phillour to Ludhiána, five miles wide, would not have to be bridged; and that the right course was to complete the embankment according to the original design, and then to guide or force the river through the bridge. I might have added that it was much better to fight the river *before* the line was opened than *after*.

Faults in design and construction of the bridge.—Three faults appear to have been committed in the design and construction of this bridge—1*st*, by the small spans used the points of danger have been multiplied, and the river has been needlessly obstructed, heavy silting above bridge being thereby encouraged, if not caused; 2*nd*, the pier cylinders have not been sunk sufficiently deep to be safe from scour; 3*rd*, too large a waterway has been given to the bridge, so that there is no proper scour through the openings by which the accumulated silt banks would be swept away, and the course of the river above and below bridge to a certain extent would have been kept straight.

Danger of the present state of the bridge.—At present the danger of the situation is this—The greater number of the bridge openings are choked up by silt deposits, and the whole dry season channel practically flows through 10 or 12 out of the 55 openings. When the river comes down in flood, the water *must* pass, and will evidently pass, by the line of least resistance, that is, it will force a road for itself, either by cutting away the silt deposits under the blocked up openings *laterally*, or by scouring out the bed *vertically*, as it has more than once unfortunately done to a measured depth of 50 or 60 feet, *i. e.*, below the bottoms of the pier foundations.

Provision of a continuous flooring recommended.—As then there would appear to be no practicable mode of *now* sinking these foundations to a further depth so as to be safe from scour, and as even if this could be done there would still be risk of failure from want of lateral stability in such long, slender, isolated columns, it only remains to secure the bed in such a manner that the flood water may find it harder to tear this up than it will be to cut away laterally the heaped up sand banks. In other words, I do not think the bridge will be safe until there is *a continuous stone flooring right across the whole bed between the piers*, which will have to be renewed steadily until it has virtually become permanent. This is, of course, the well known plan by which Madras Engineers have always secured the shallow foundations of their bridges, as opposed to the Bengal plan of deep foundations and no flooring. The difficulty in the present case arises from the absence of good stone in the neighbourhood, and the cost and time required for procuring it.

Kinds of stone used.—What is now being used is either (1) block kankar dug in various places, and averaging Rs. 12 per 100 cubic feet on the work; (2), boulders brought down the river by boat, costing Rs. 10 per 100; (3), stone from Rúpar brought in trucks by the branch line from Doráha, costing Rs. 15 per 100.

Of the above the block kankar appears of good quality and fair size generally; but there is no doubt that without *rigid supervision* a very worthless material might easily be furnished by the Contractors, which would simply be useless for the purpose required.

The boulders are nearly all small, and can only be properly utilized by putting them into crates and nets, as is now being done. If thrown in loose, they will simply be carried away.

The stone from Rúpar is of good quality, but only a small quantity is procurable without interfering unduly with the Canal works. It should be quarried in the largest possible blocks and reserved for protecting the most exposed and dangerous places.

Flooring is to a certain extent being formed.—By a section very carefully taken quite lately on the spot, it would appear that the stone thrown round the piers during the various years has gradually spread so as to meet, thus forming a flooring under the several spans. As yet, however, this flooring is, of course, slight, and neither in width nor depth sufficient to resist the scouring action of the stream when in flood. And it appears to me that the provision of a sufficient flooring, such as has been described above, should now be systematically undertaken until the whole is made safe.

Present state of the bridge.—At present the state of the case is this—Out of the 55 spans of which the bridge consists, 40 of them (counting from the Phillour bank) are now (March) dry, and silted up to various depths below the girder. The river is now running through the next 10 spans, the remaining five being dry. Of the 10 spans through which the water is now flowing, the four nearest the Ludhiána end have no great strength of current through them, a considerable silting up having taken place by means of the stone bunds and tree spurs which have been constructed since October last, in order to check the action of the river towards this bank, and to throw the water more towards the middle of the bridge.

The effect that has been thus produced appears to me very promising, and tends to show that, had the bridge been made with the restricted waterway originally intended, it would have been quite feasible to have guided the river through it, as has been done in other cases. The channel appears to be widening itself gradually by cutting away the sand banks; and if this action continues for the next two months, there is good hope that the main channel may be flowing through a sufficient number of spans to prevent any severe scour at one or two of them.

Protection of the piers.—The piers of the bridge are now being protected by the Chief Engineer by means of a double row of wooden crates filled with stones, placed at a distance of 30 feet from the pier all round, laid at as low a level as they can be placed, the interval between the crates and piers being filled with *trungahs* or nets of stone, and this method, in the absence of large stone blocks, appears to me the best way, though there is some fear lest, when scour takes place and the crates fall down, they may break up under the weight of stone and force of the current. The Chief Engineer proposes to protect all the piers in this manner, working at first, of course, on those more immediately liable to be attacked, and he hopes, before the working season is over, to have nearly all thus protected.

Detailed state of the bridge.—Of the spans nearest the Ludhiána end, the three nearest the abutment, *i. e.*, up to pier No. 56, were filled up, when the girders were removed to replace those that were lost during the flood of August last.

From piers Nos. 56 to 50 the spans were, I understand, filled up three or four years ago to a certain height, the filling being protected by stone pitching, which filling or flooring during the floods of last year virtually acted as a spur, the current running parallel to it, and so acting with increased violence against the next spans which were not thus floored, and so scouring out two piers. The object of partially filling up the eight spans nearest the Ludhiána end was evidently to resist the set of the river upon this end of the bridge, and seems to show how soon it had been seen that the provision of increase of waterway at this end was a mistake.

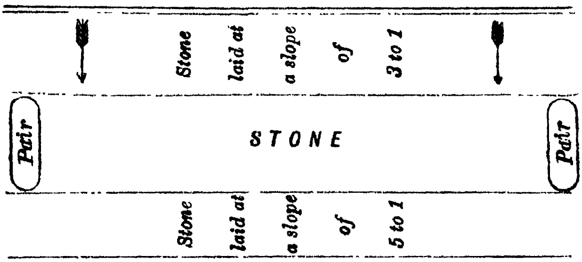
These piers (56 to 50) are at present being protected in the above manner, and will all be completed before flood. And the action of the stone bunds and tree spurs, as above explained, has been so far satisfactory, that there is no present danger of this portion of the bridge being attacked.

The next two piers, Nos. 49 and 48, were the two that were lost last year, and which have been replaced in the manner explained in Chief Engineer's No. 419, copy of which is attached, and which was approved by my predecessor, Colonel Pollard. It consists, as will be seen by looking at the plans sent up, in replacing the brick cylinder piers by a cluster pier of four cast-iron columns filled with concrete, resting on a platform which is virtually carried on a *pierre perdue* foundation. Its permanent safety, supposing it to be again attacked by the river, will, I think, depend on the efficiency of the flooring provided between the piers to protect it from scour, and on the ability of the slopes up and down-stream to resist the action of the water, and, if it succeeds, will show, I think, that with an efficient flooring the piers of the bridge would be safe, even if sunk to a less depth than they now are. To ensure this the flooring should be laid with good sized blocks, the largest being reserved for the upper surface and for the protection of the up-stream slope. At present this portion of the bridge is a good deal protected from severe action by the tree spurs above-mentioned.

The next portion of the bridge between piers Nos. 47 and 42 is that which, *according to present appearances*, will be most severely tried this year, not only because the main stream is now running here, but because the adjacent stone flooring of the mended spans will have a tendency to act as the blocked up spans did last season. To guard against this, the holes round the piers have been filled up with stone to bed level, and on this the protective work of crates and nets has been placed as above described, while the flooring of the partially blocked up spans has been dished from the east end downwards towards the centre, so as to admit a certain flow of water over it.

To fill up the spans themselves to floor level with stone in such a depth of water as is now running, and with the present means available, would be almost impossible, while, even if carried out, it would not be efficient unless the flooring was *at once* continued right across the river, because the new flooring would only deepen the action of the water on the next spans.

The remainder of the bridge from pier No. 42 to 1 is at present dry; the piers are being gradually protected, as above described, in addition to the quantities of stone (from 10,000 to 40,000 cubic feet) which have been thrown round them at various times. There is no flooring between these piers except (as already explained) what has been partially formed by the meeting of the masses of stone thrown round the piers, but which in my opinion should be supplemented by masses of stone systematically laid up to within say 3 feet below fair bed level, and for a width not less than the length of the pier (12 feet 6 inches), with a good slope both up and down-stream.



The thickness of such a flooring must, of course, be determined by the river itself, *i.e.*, renewals of stone must be made until all scouring action ceases.

Further restriction of the waterway.—When the floorings are completed, it will, I think, be found perfectly expedient to take away more of the spans from the Ludhiána end, closing the bank, and contracting the waterway, so as to secure a proper and equable scour through the whole length of bridge, or constructing a bank of stone in an oblique direction from the east abutment up the left bank, as has been done in the case of the Chenab. Nothing would tend so much to keep the river straight in its course above. So long as it has so large a width to wander over, it is impossible to say at what point in the valley (between Phillour and Ludhiána) it may not try to force its way through the line of railway.

It may perhaps be asked whether the cost that will have to be incurred in putting in the enormous quantities of stone that will be required for this flooring will not be almost as great as would suffice to build new piers sunk to a proper depth, and it is quite possible it may be the case. The cost of the flooring, however, will be spread over several years, and, if gradually and systematically done, there should be no waste of money, though, until it *is done*, the bridge will always be a source of anxiety.

Object of this Note.—The object of the present Note is—1*st*, to show how matters at present stand, and what in my opinion are the causes of danger; 2*nd*, to systematize as much as possible what is being done to guard against that danger. For this latter purpose I would urge that special attention should be directed to getting the largest possible blocks of stone; and that as soon as the well piers are all protected in the manner proposed by the Chief Engineer, the stone flooring between the piers should be systematically laid down. It is evident that this should not be done span by span; otherwise, as already pointed out, these floorings would act as spurs to deepen the action against the spans adjoining them. It appears to me that the flooring should be carried on as far as possible *simultaneously*, at any rate over the portions of the bridge immediately attacked, only large blocks of stone or (in their absence) very strong crates being used (so that whatever is put down may not be swept away), or by taking advantage of each portion of the river as it happens to be laid dry in successive cold seasons, (if necessary silting it up by artificial means,) putting down a flooring of considerable thickness, which, of course, must be renewed as it sinks.

Fortunately, the Phillour end of the bridge may, I think, be considered naturally secure, and the Ludhiána end will, I hope, in time, by working on a system, be artificially made secure also. My fear is, that unless systematic means be adopted, much of the heavy expenditure incurred will be thrown away by pitching in stone which may be swept away, and in places where it can do no good.

I may add, that the Chief Engineer, Mr. C. Stone, to whom I have read this Note, concurs generally in its ideas and recommendations, which is all the more important; that I fear the Company will shortly lose the benefit of his experience and services for a time owing to the state of his health, and I am anxious that what we both concur in should be acknowledged and acted upon by his successor and subordinates.

Dredger.—Mr. Stone also strongly recommends the employment of a steam dredger to cut channels through the silt banks in the cold weather, and assist in regulating the equable flow of the water through the bridge; and I am inclined to think that the employment of such a means would be a very valuable auxiliary, notwithstanding the danger which I cannot help fearing of the early freshets silting up the dredged out channels. This will, however, be separately discussed when the estimate is sent up.

Copies of Chief Engineer's letters describing in detail the means employed for closing the late break and those now being carried out for protecting the piers are appended to this Note. My predecessor has, I believe, already recorded his opinion of the ingenuity, ability and untiring energy with which the work of restoration was carried on by Mr. Stone and his subordinates.

Re-construction Works in the East Beyn and East Beas Valleys, Scinde, Punjab and Delhi Railway.*

Dated 8th October 1878.

From—Charles Stone, Esq., *Chief Engineer.*
To—Agent, *S. P. and D. Railway Company.*

"*Flood Damages 9th and 20th August* 1878."

"*Beas Valley.*"—The serious destruction to the Company's bridges and works in the Beas Valley, again necessitates the re-opening the question of more flood openings in the valley. Results anticipated by me since the introduction of the causeway system in the Grand Trunk Road above the line of Railway, and commented upon flood season after flood season in reports and letters up to the present year inclusive. Before entering upon the question of amount of waterway to be given in lieu of the destroyed bridges, I venture to lay before you extracts from such reports and letters (Appendix A) not from any intention of further discussion, but in support of my views, that the time would come by the extension of the causeway system (and thereby drawing the river in flood towards them), when it would become necessary to *viaduct* the whole valley. And also to show that in not providing sufficient waterway under the line of Railway to meet the increase in the Grand Trunk

* *Note.*—Plate to Article No. CCCV. is a general plan of this Valley.

Road was from the uncertainty of what the Department Public Works intended doing; first accepting my proposals to raise the causeways, and last year withdrawing that acceptance, when it was too late for me to do more than build a new bridge of two spans of 50 feet at the Chatar Singh Nallah (which has fortunately stood), doubling the waterway of the Ramídi, and strengthening the Hamíra; the two latter were entirely destroyed in the last floods.

Originally the Company's Engineers had to deal with the Western Beyn river and defined nallahs, carrying a moderate amount of spill in high flood of the River Beas.

That period has now passed, and by the encroachment of the river so much further eastwards, we have now to accept the conditions anticipated by me, and to deal with the waterways in the Beas Valley to meet what I term *a branch of the Beas river in high flood.*

To show the large increase of waterway made by the Engineers of Department Public Works in the shape of causeways, since the construction of the Railway, and to endeavour to arrive as far as possible at the amount of waterway required, I would invite attention to the accompanying sections of the waterways at the Grand Trunk Road in 1871 and 1878.

The original openings of 1866 are shown in black, copied from records in my office. The 1878 sections are shown in red, and were taken last cold season with the very object of laying before you the enormous difference or increase of water passage that we had to contend against. The 1871 area aggregates 6,313·54 superficial feet, the 1878, 26,650·49 superficial feet up to flood line of this season; but it will be seen that this is not the limit, there is nothing to prevent its rising much higher.

Appendix C.—Is a statement showing the original amount of waterway built for the Railway, *viz.*, 8,663 superficial feet, and the increases from time to time up to the serious destruction which occurred on the 19th and 20th of August last.

Appendix D.—Is a statement showing the amount of waterway, *viz.*, 17,992 superficial feet required to assimilate with the area of the present or existing state of affairs on the Grand Trunk Road.

In Appendix D—It will be observed the description of girders are given to correspond with the girders of the bridges destroyed, hoping that some at any rate of these may be recovered. The temporary diversions having been completed, my staff are now engaged taking soundings and notes, with the view to ascertain, if it is possible, or worth the expense to endeavour to raise them; and on the success or failure of the attempt, Appendix E will show the number of girders required of the same length as those of which the bridges were constructed; assuming as shown under "Remarks" that the Government adopt my proposal, dated 13th September 1878, to dismantle or remove eight spans of the Sutlej Bridge. In anticipation of our requirements, I forwarded to the Chairman, Board of Directors, outline drawings of the description of girders that might be required, under initial letters to prevent mistake in transmission of orders by telegraph. These drawings are by this time in the hands of the Directors, or should be in a few days. And in my letter of instructions I requested that our Consulting Engineer in England should hold himself in readiness to despatch (upon receipt of telegram) with as little delay as possible the girders required.

An alternative to having girders as noted in Appendix E., would be to span the rivers and large nallahs with the large girders from the Sutlej, and what might be recovered from destroyed bridges, and to supplement them by a standard girder, say of 30 feet, to be used as multiples to viaduct both the Beas and East Beyn Valleys, (a drawing for this girder has also been prepared for the guidance of the Board.)

I would strongly advise this alternative, it would be cheaper, more expeditously built, and in case of future accident, much more easy to recover, less loss if not recovered; and duplicates could be made in the Railway workshops, should increases at any time hereafter be necessary.

The East Beyn Valley.—At present the full detail of what is required here I have not had time to work out, as it is a matter requiring some considerable attention, taking the enormous rainfall of 16 inches in 24 hours in the district, added to the drainage area of the Hoshiárpur hills which comes down with a rush.

Approximately we can prepare for this; at any rate a minimum number of girders should be ordered.

The East Beyn Railway bridge destroyed was one centre span of 110 feet, and two side spans of 82 feet girders. The piers carrying these are destroyed; the abutments are standing, and to all appearance sound; and for this bridge (as new piers could not be got in at their former position)

I intend (assuming the abutments are found all right upon a minute inspection) to sink one centre pier, and span the river with two spans in lieu of the three above referred to; and if the fallen girders should be recovered, these would be used in the Beas Valley works. And in addition to the main bridge to put in multiples of 30 feet girders as a viaduct between it and the new 40 feet erected the past cold season, and similarly eastwards towards the double 10 feet girder opening, also put in last cold season.

A large amount of bridging must be provided for; and there is no reason why a minimum quantity of girder work should not be ordered at once, upon its being decided what description of girders may be used, and subsequently decide upon the balance or maximum.

The amount of work to be carried out, it will be seen, is very extensive, and which must be finished before the 30th of June 1879. And unless I have immediate sanction for the girders and provisional sanction to collect material, such as making curbs for wells, brick making, &c., I cannot be responsible for the execution of the work by the flood season of 1879. And in addition to this immediate provisional sanction, I trust that a liberal amount of discretionary power be given me (of course under the supervision of the Government Consulting Engineer) to enable me to push on the work without a day's delay. I have already arranged as a temporary measure the re-disposition of my Engineering staff, so that by an equal division and distribution of the work, the present staff can carry it out, with a good number of Inspectors.

Since writing the foregoing, I find from copy of a letter received from Superintending Engineer, 2nd Circle, Punjab, to his Executive Engineer, forwarded to me for information. That it is the intention of the Department Public Works to increase the waterway on the Grand Trunk Road by more causeways; evidently accepting the inevitable. The information is too brief to enable me to include this proposed extra in my statement of girder requirements, but it shall follow as a supplement to the present list, as soon as I am in possession of sufficient data.

No. 4582R, dated 25th October 1878.

From—*The Government of India, P. W. Department.*

To—MAJOR J. G. FORBES, R.E.

I am directed to request that you will at your earliest convenience proceed to the Beas and Sutlej Rivers, and, after careful personal examination of the railway river crossings, as well as the valleys, for some miles above them, place yourself in communication with the Agent, Scinde, Punjab and Delhi Railway, Mr. Stone, and the Consulting Engineer for State Railways, with a view of submitting in conjunction with them, proposals for preventing any further breaches of the railway from the overflows of these rivers.

You should also report what measures are best, in your opinion, for attaining and securing a straight current, in a perpendicular direction, to the railway bridges at the Sutlej and Beas crossings. It is proposed to reduce the size of these bridges, but it is evidently not desirable to do so, if such reduction necessitates the construction of new bridges at some other points in the valley.

Note on the Waterway of the East Beyn Nadi. BY MAJOR J. G. FORBES, R.E.

Dated Lahore, 30th November 1878.

Discharge through bridge.—The Railway bridge over the East Beyn consisted of one centre span of 110 feet and two side spans of 82 feet girders.

The actual superficial amount of waterway during the height of the flood of 19th and 20th August 1878, just previous to the destruction of the bridge, was 7,646 square feet.

The afflux on the bridge was 3 feet, and with a velocity of approach of 5 feet, the mean velocity through the bridge would be 9·95 feet per second; and the discharge 76,078 cubic feet per second.

Discharge through flood openings.—On the right bank there are two flood openings, A and B, with waterways of 396 and 640 superficial feet. The afflux on A was 3 feet, and on B 2 feet. With velocities of approach of 2 feet and 1 foot, the mean velocity through A would be 8·90, and through B 7·14 feet per second; and the discharge through A 3,524 cubic feet, and through B 4,570 cubic feet per second.

On the left bank there is one flood opening C, with a waterway of 240 superficial feet. The afflux was 2 feet, and with a velocity of approach of 2 feet, the mean velocity would be 7·19, and the discharge 1,726 cubic feet.

Total discharge through bridge and flood openings.—The total discharge of the river would therefore be 85,898 cubic feet, as follows :—

Through bridge,	... ...	76,078	cubic feet per second.	
" A,	... ...	3,524	"	"
" B,	... ...	4,570	"	"
" C,	... ...	1,726	"	"
Total,	...	85,898	"	"

This calculation, it will be noticed, is based on the probable supposition that the bridge and banks stood until the maximum flood was attained.

Discharge through breaches.—But the bridge was destroyed, the flood openings damaged, and large breaches made in the bank. Working out the discharge through the breaks, after the destruction of the bridge, and when the maximum flood was still running down, it appears from the section that the superficial waterway in the centre of the stream was 8,200 feet. The mean velocity through this portion may be taken at 4 feet, and the consequent discharge at 32,800 cubic feet per second.

On the right bank there is an additional amount of waterway F, aggregating 12,000 superficial feet, with a probable velocity of 2 feet; and on the left bank a superficial area G of 15,600 feet, also with the same velocity; the discharge through F and G therefore would be 24,000 and 31,200 cubic feet. The total discharge of the river then by this approximation would be 88,000 cubic feet per second.

Discharge by Dickens' formula.—Dividing the catchment basin of 812 square miles into three zones roughly parallel to the hills, and applying Dickens' formula, with the coefficients 825, 412 and 206 for the north or hill, the central and the southern zones, according as the slope of the country decreases, we find the following discharges :—

For hill zone,	... ...	44,400	cubic feet per second.	
" central zone,	... ...	22,100	"	"
" southern zone,	... ...	18,600*	"	"
Giving a total discharge of	...	85,100	"	"

Discharge from rainfall.—Referring now to the rain gauge registers, it appears that on the 18th August there was a fall of 12 inches at Jullundur, and of 4·9 at Hoshiárpur on the west of the catchment basin, and of 4·5 inches at Garhshankar to the east of the basin. This would give a total fall of 232,000 cubic feet per second. Previous to the 18th there had been little or no rain for some time; the usual amount of ·35

* Equivalent to a coefficient of 560 for total area.

of the above amount, or 81,200 cubic feet per second, may therefore be taken as the probable discharge of the nadi on the first day of the flood.

On the 19th August 4·5 inches fell at Jullundur and 14·2 at Hoshiárpur, but there was no rain in the eastern half of the catchment basin. This would give an amount of 167,700 cubic feet per second to be disposed of. As the ground was wet with the previous day's rain, if we take ·50 as the proportion discharged, the flood in the river on the second day would be 83,850 cubic feet per second.

Discharge by O'Connell's formula.—These calculations can again be checked by the aid of O'Connell's formula; but in order to use this we must know the modulus of discharge of some analogous river. The only one approaching to the same conditions as the East Beyn is the Sohan nadi, which crosses the Lahore and Peshawar Road. The value of M for this stream, as calculated by Colonel O'Connell, is 141. Its catchment basin is 573 miles, and its slope is about 9 to 7 of that of the East Beyn, from which data the modulus of the latter would be 109. Applying this the discharge would be 83,875 cubic feet per second.

Probable discharge.—Abstracting the results of these approximations to the true discharge, we have—

Through bridge and flood openings,	85,898	cubic feet	per second.
Through breaches, ...	88,000	"	"
By Dickens' formula, ...	85,100	"	"
By rainfall, ...	83,850	"	"
By O'Connell's formula, ...	83,875	"	"
Giving a mean discharge of,...	85,345	"	"

or 105 cubic feet per second per square mile of catchment basin, which is equivalent to a fall of 4 inches of rain over the entire drainage area of 812 square miles, without allowing any loss by absorption, &c.

Waterway required.—Accepting 85,000 cubic feet as the probable discharge of the East Beyn, in order to pass this amount with a mean velocity of 6 feet per second, a superficial waterway of 14,167 square feet would be required, or 17·50 square feet per square mile of catchment basin. With a depth of water not exceeding 25 feet, or 5 feet less than the height of the late flood, this would entail a lineal waterway of 567 feet.

Waterway given.—The actual amount of waterway given was 9·75 superficial feet per square mile of basin. This, although amply sufficient in the case of ordinary streams running down a Doáb, is, as is proved, entirely inadequate for the great floods which occasionally come down rivers, like the East Beyn, which are at a distance of 25 miles only from the foot of the hills.

Waterways on the East Indian Railway.—The average amount allowed for the waterways of the hill streams crossed by the East Indian Railway in the Rájmahal District is 43·40 square feet per square mile of catchment basin; but this is calculated on Cautley's formula, which gives a waterway of about one-third in excess of the actual requirement, and besides this, these streams are crossed in, or at the foot of, the hills; and the catchment basins are small.

Waterways in the Gandak embankments.—In the outlets in embankments in the lower part of the Sarun District, which is about 50 miles from the hills, 10 superficial feet per square mile of drainage area was originally given; but this was found to be too small, and from 13 to 14 superficial feet is now allowed.

Probable correctness of waterway recommended.—Judging from these facts, the above amount of 17·50 superficial feet per square mile of catchment basin may, I think, be safely taken as the proper discharging capacity of the Railway bridge over the East Beyn.

Note by COL. J. G. MEDLEY, R.E., *on the requisite Waterway to be given to the East Beyn River where crossed by the Scinde, Punjab and Delhi Railway.*

Dated Lahore, 4th December 1878.

1. The bridge over this river having been entirely destroyed during the floods of August last, as already reported to Government, and in such a manner that the waterway provided was clearly inadequate, it becomes necessary to consider what size of bridge will be needed, and that without loss of time, so that the Chief Engineer may proceed without delay to complete the work before next floods.

2. The waterway provided on the first construction of the line (11 years ago) has hitherto proved sufficient, and Colonel Pollard's report on the breaks of 1875 does not even mention the East Beyn. In 1876, however, a heavy downpour of rain at Jullundur caused such a rise in the river, that the water flowed over the bridge planking, and it was therefore determined to raise the bridge three feet, and to slightly increase the subsidiary waterways. This was accordingly done, but, as the result has shown, the further provision has been wholly inadequate.

3. Major Forbes' Note gives his conclusions (arrived at by several inde-

pendent calculations) that the total discharge to be provided for is 85,000 cubic feet per second, requiring a provision of 17·50 square feet per square mile of catchment basin, instead of 9·75 as previously given.

4. To provide for this, the Chief Engineer has already been authorized to telegraph to England for the girders of 136 feet span which he requires to bridge the space between the present abutments still standing in lieu of the three spans which have been swept away; these will provide 272 feet. To these may be added two girders of 110 feet which the Chief Engineer proposes to take from the east end of the Sutlej bridge, and which Major Forbes and I both concur with him in thinking may be advantageously reduced in length by at least eight spans. These will complete the bridging of the main channel of the river as enlarged by the late flood, and will make a total provision of 492 feet.

5. This amount, with a depth of 25 feet,* as assumed by Major Forbes, and a velocity of six feet per second, will pass 73,800 cubic feet, leaving 11,200 feet to be provided for either in the main channel, or by flood openings on the right and left of the main channel, of which 76 lineal feet are still standing.

6. I object to any further widening of the main channel, because the extra openings would certainly get silted up, and because the requisite waterway can be given so much more economically by flood gaps. The only danger of the latter is, of course, that they may draw the main stream towards them; but as they will only act during very extraordinary floods, and after three-fourths of the full waterway is passed down the main channel, I see no reason to be alarmed on this score.

7. These flood gaps will give a depth of 10 feet of water, and, assuming a velocity of five feet, would require 224 lineal feet of opening, of which 76 feet still exist, so that 148 feet remain to be added. These might be given by five of the 30 feet girders which Mr. Stone proposes. I will speak of the supports for these flood openings presently.

8. I do not, however, feel confident, after fully considering the matter, that we shall even then be safe with a stream of this very dangerous character, the floods in which are produced by such exceptionally heavy falls of rain. In his calculation from Dickens' formula, Major Forbes assumes the constant (825) to be true only for that portion of the catchment basin in or close to the hills, and reduces its value considerably for two-thirds of the

* The bottom of the girders should be 5 feet above the flood line, or 30 feet above bed.

area, as he considers that the employment of the full constant, except for drainage basins in or close to the hills, will give extravagant results.

9. Now referring to the bridge over the Sohan River, quoted by Major Forbes (in page 361) as a somewhat analogous case, I find (*see* Roorkee Civil Engineering Treatise, Vol. II., 2nd edition, page 105) that the flood discharge was estimated at 91,000 cubic feet from the cross sections, being nearly up to the full amount (95,700) required by the Dickens' formula, while the waterway provided was 18,900 superficial feet up to arch springs, being 33 square feet per square mile of basin. Major Forbes says the Sohan is virtually a hill torrent, having a compact rocky basin; but the distance of the Sohan bridge from the hills is not less than that over the East Beyn. No doubt the rocky bed will ensure a greater full discharge through the bridge than in a stream like the East Beyn with its sandy soil, but the greater fall in the former case would ensure a discharge through a less area, and I doubt whether so much is lost by absorption in a stream like the East Beyn, in the case of a heavy plump of rain, occurring as it does when the ground is already thoroughly soaked.

10. Take again the Márkanda, which is perhaps a more strictly analogous case. The drainage basin is 350 square miles; the waterway provided at the Grand Trunk Road bridge is 12,876 superficial feet, or 36 square feet per square mile. Here too, doubtless, the catchment basin is more compact (though all other conditions are the same), and therefore I would not propose so large an allowance for the East Beyn as 36 feet. The discharge of the Márkanda by the Dickens' formula would be 66,825, and, it is said, no higher discharge has yet been recorded than one of 48,000 feet (in 1845),* but this is of course no proof that there may not be a greater flood than this.

11. I will endeavour to get later records of Márkanda floods, and to examine the case of the Gaggar and any other streams I can get; but, meanwhile, while fully assenting to Major Forbes' view that the Dickens' coefficient gives too large results if applied to streams strictly in the plains (like those in the Ganges Doáb, which are virtually parallel to the drainage of the country), I cannot see, from the instances I can collect of discharges at points 20 or 30 miles only from the hills, where the drainage is crossed at right angles, that the coefficient is too large in a country

* I measured a flood of about this volume in 1865.—A. M. B.

like the Upper Punjab, where we are exposed to heavy plumps of rain.

12. In the present case we have had such full warning, and the results of failure are so disastrous, that I really do not care to risk anything. I would gladly compromise, if I could, by making spill gaps on both sides of the bridge, but for this, as the section will show, there is no room.

13. The discharge to be provided for, if the full coefficient required by the Dickens' formula be given for the whole drainage area, will be 125,000 cubic feet instead of 85,000 as computed by Major Forbes, or 25 square feet per square mile of basin instead of 17½; this is equivalent to a fall of one inch in an hour over 190 square miles (about one-fourth the catchment basin), and this seems to me not an impossible amount of rainfall.

14. If this extra amount is provided in the main channel, it would require five girders of 110 feet instead of two as above proposed; it would, however, be more cheaply given by adding 800 lineal feet more of flood spans, or, say, 27 extra 30 feet girders.

15. The whole waterway of the East Beyn Valley would then be—

		Lin. ft.
2 girders of 136 feet,	... ... =	272
2 " 110 "	... ... =	220
32 " 30 "	... ... =	960
Small existing girders,	... ... =	76
		1528

lineal feet in a length of 1½ miles, or about one-fifth of the breadth of the valley,—a large but not, I think, an extravagant amount.

16. With regard to the flood openings, which would only come into use during excessive floods, the Chief Engineer proposes 30 feet girders from England, or 16 feet girders made out of old rails as the most economical expedient, and he suggests cast-iron screw piles to carry them. I understand, however, that trouble has been experienced on the Punjab Northern State Railway viaducts with screw piles from the vibration of trains, and I am inclined myself to prefer masonry piers, either sunk on wells 15 feet deep, or with inverts, or a concrete flooring four feet below the surface, and defended by apron walls, front and rear, as may be found most economical. The question of the best unit of waterway for the large amount of flood openings that will be required in both the East and West Beyn Valleys is one that must depend greatly on the comparative cost of different methods, and which I have no doubt the Chief Engineer will carefully investigate before deciding.

17. The cost of the 960 feet of flood opening is, I believe, estimated by the Chief Engineer at less than Rs. 100 per running foot of waterway, or, say, one lakh altogether. The cost of the large bridge should not exceed Rs. 400 per running foot of waterway, or, say, two lakhs, making a total of three lakhs.

I now send the present Note of Major Forbes' to Mr. Stone for him to record his opinion if he wishes, and will ask Major Forbes to add anything further that occurs to him, when the matter may be referred to Government of India for decision.

Meanwhile, work can proceed to the extent, at any rate, of the waterway proposed by Major Forbes, and to which I understand the Chief Engineer to assent; proper plans and estimates will of course be prepared and submitted.

I would also ask the Chief Engineer, in the case of this and similar waterways which it may possibly be found necessary to increase, to consider whether the abutments cannot be treated as piers (as carried out on Mr. Molesworth's plan on the Indus Valley Railway) with loose masses of stone in lieu of wing-walls, at any rate for the present, so as to save time and money.

Note on the Waterways of the West Beyn and other Bridges in the Beas Valley. By Major J. G. Forbes, R.E.

Commencing from the Beas bridge (which is at 59½ miles from Lahore), the bridges on the Scinde, Punjab and Delhi Railway in the East Valley of the Beas are as follows:—

Name of Bridge.	Lineal waterway.	Superficial waterway.	Distance from Lahore.			During flood of 19th and 20th August 1878.
	Feet.	*Square feet.*	*M.*	*Ch.*	*Links.*	
Fattuchak, ...	109	977	61	70	40	Stood.
Mandorah, ...	55	495	62	52	10	Destroyed.
Hambowál, ...	102	1,530	64	2	75	Ditto.
Ramídi nallah, ...	101	1,166	64	63	43	Ditto.
Ramídi, ...	202	2,242	65	49	42	Ditto.
West Beyn, ...	150	1,350	66	31	34	Ditto.
Chatar Singh, ...	96	1,016	67	10	0	Stood.
Hamíra, ...	193	2,093	67	26	70	Destroyed.
Total, ...	1,008	10,869				

This amount of waterway gives a mean depth of about 10 feet on floorings of bridges, and with a velocity of six feet, a capable discharge of 65,000 cubic feet per second.

The Fattuchak, Mandorah and Hambowál practically drain one catchment basin, the area of which is 14 square miles. The waterway given to the bridges is 3,002 square feet, or 214·43 square feet per square mile of basin.

The basin of the Ramídi comprises 55 square miles. The waterway given is 3,408 square feet, or 62 square feet per square mile of basin.

The catchment basin of the West Beyn is 664 square miles, including about 10 square miles of drainage area belonging to the Chatar Singh and Hamíra, which act as flood channels of the West Beyn. The waterway allowed is 4,459 square feet, or 6·71 square feet per square mile of basin.

Now taking out the probable *maximum* discharges of these catchment basins, and commencing first with the Hambowál, with its small drainage area of 14 square miles. If we suppose a similar fall to that which took place at Jullundur on the 18th August 1878, *viz.*, 11 inches in 14 hours, to occur over the whole of the basin, and take ·85 as the amount passed off (the largest coefficient known is ·89, and this was for a drainage area of three square miles), we get a discharge of 6,018 cubic feet per second, which, as might be expected with such a small basin, agrees with the discharge by Dickens' formula, with the full coefficient of 825, which gives 5,970 cubic feet per second.

Again, applying Dickens' formula, with the full coefficient to the 55 square miles of the Ramídi basin, we get a discharge of 21,000 cubic feet per second, which also agrees with that obtained from the rainfall, supposing ·78 of the amount to be carried off.

The full coefficient is, I consider, inapplicable to the case of the West Beyn, with its large catchment basin of 664 square miles. In my Note on the East Beyn I took 560 as the proper coefficient for that river. I considered it was so well known a fact that the Dickens' formula was not applicable with its full coefficient, except for the discharges of hill streams, and of small catchment basins, that I did not enter into reasons for the reduction; but, as it appears there is still a lingering belief in the entire applicability of the Dickens' formula, and as I have been invited to enter more fully into the question, I propose doing so hereafter, as it would be extraneous to the object of this Note to do so now.

Accepting 560 as the proper coefficient for the East Beyn, as the discharge calculated by it agrees with that derived from the rainfall, and from the flood through the bridge and breaches, as also by O'Connell's formula, I find the coefficient for the West Beyn* would be 619. Applying this, we get a discharge of 81,000 cubic feet.

Checking this by the O'Connell formula, with a modulus of 115, we find the discharge to be a little more than 80,000 cubic feet.

Taking the larger discharge of 81,000 cubic feet per second as approximately correct for a *maximum*, it is equivalent to a rainfall of nearly 5 inches over the entire catchment basin of 664 miles, or about one-fifth of an inch per hour. Colonel Dickens for *small* areas of 50 miles allows only half an inch per hour.

From the above data then I consider it will be safe to take the *maximum* discharges of the different basins as follows, *viz.* :—

Hambowál,	...	...	...	6,000	cubic feet	per second.
Ramídi,	...	...	...	21,000	„	„
West Beyn,	...	...	...	81,000	„	„
		Total,	...	108,000		

But on the 19th and 20th August these basins were not in *maximum* flood. Only 4·5 inches of rain fell over the Hambowál and Ramídi areas, which, with coefficients of ·85 and ·75, give discharges of 1,433 and 4,954 cubic feet per second respectively.

On the first day there was a fall of 4·5 inches of rain over two-thirds of the catchment basin of the West Beyn, and of 6 inches over the remaining one-third. Taking ·35 of the amount as the quantity passed off, the discharge would be 31,500 cubic feet per second. On the second day there was a fall of 7 inches over one-half the area, and with a coefficient of ·50, this would give a discharge of 31,000 cubic feet per second.

In addition, however, to the amount due to rainfall, there was a considerable spill from the River Beas, and in order to obtain some approximation to the quantity, we must find the amount passing through the bridges.

* Taking 560 for the East Beyn, the coefficient for the Sohan would be 750, and the discharge 89,600 cubic feet, which agrees with that assumed, *viz.*, 90,000 cubic feet, whereas the full coefficient 825 gives a discharge of 96,700 cubic feet per second.

Working this out by the afflux, &c., the probable quantities discharged were :—

		Discharges per catchment basin.	Due to rainfall.	Due to spill.
Fattuchak, ...	7,816			
Mandorah, ...	4,207			
Hambowál, ...	13,387			
		25,410	1,433	23,977
Ramídi nallah, ...	10,401			
Ramídi, ...	19,617			
		30,018	4,954	25,064
West Beyn, ...	12,744			
Chatar Singh, ...	8,128			
Hamíra, ...	19,758			
		40,630	31,500	9,130
Total, ...	96,058	96,058	37,887	58,171

Instead of 96,000 if we take 100,000 cubic feet per second as the actual discharge, and consider 60,000 cubic feet per second as the spill from the river, we shall probably get a very close approximation to the true amount of *maximum* spill, as on the 19th and 20th August 1878 the Beas gauge was one foot higher than what used to be considered the highest flood, that of 1875.

Although very unlikely to occur, if we accept the possible as the probable, and say that *all* the catchment basins and the river are discharging their maximum at the same moment, the waterway that will have to be provided must be capable of passing 108,000 + 60,000 = 168,000 cubic feet per second, which, with a mean velocity of 6 feet, would require 28,000 square feet of opening, and with the depth of 10 feet as now given (*see* page 366), which possibly is too much, a lineal waterway of 2,800 feet, or nearly three times as much as that originally provided.

Reverting to the discharges of the catchment basins during the late floods, as shown above, it will be seen that out of the 58,000 cubic feet of spill entering the valley, 49,000 cubic feet passed off by the Hambowál and Ramídi basins, and only 9,000 by the West Beyn. At the first glance I thought I had possibly made some mistake in taking out the quantities; but on looking at the section it will be seen that the breaches on the Railway *are entirely confined to the immediate vicinity of the Hambowál and Ramídi nallah bridges* in a distance of $1\frac{1}{2}$ miles, *viz.*, from mile $63\frac{1}{4}$ to mile $64\frac{3}{4}$. In page 367 it will be seen that 214 and 62 square feet of waterway per square mile of catchment basin was given; and notwithstanding these large amounts, the breaks occurred, thus showing that an undue strain was brought to bear on this part of the line. The cause of this strain is at once seen by an inspection of the map: the Ramídi and Mandorah are actually flood channels of the river. The Hambowál is also practically one, and, besides having to carry off its own share of the burden, has to pass some of the spill of the Mandorah. This is clearly shown in the longitudinal section up the east bank of the Beas, and in the Chief Engineer, Scinde, Punjab and Delhi Railway's reports, dated 4th November 1875 and 10th December 1875, on the flood of that year, in which both the Hambowál and Ramídi bridges, as well as the Hamíra, were destroyed, the Ramídi having previously been carried away in 1871. Thus in eight years this bridge has been three times destroyed, and the Hambowál has fared little better. The Hamíra is in the lowest part of the valley of the Beas, to which tends all the upper spill of the river near the Beyn jhils, *vide* page 371; and besides this, the Hamíra bridge has to carry off a considerable portion of the West Beyn floods.

Considering these facts, it is not surprising that these three bridges, and the Hambowál and Ramídi in particular, should have been such a constant source of trouble.

The *fons et origo mali* is undoubtedly the flood of the Beas entering these channels, and the obvious remedy is to keep out the spill, at all events from this part of the line. Although I am far from being an advocate for embankments along rivers, I consider it would be very advisable to construct one on the left bank of the Beas for a distance of 16 miles from the Railway bridge to near the village of Rúrah (opposite Govindpur), between which points the high cliff of the river comes close down to the water's edge on the right bank, and there are apparently no villages to be damaged by any possible increased height of flood, which, however, I believe, will practically not take place, judging from the fact that the Gandak has been embanked for some years for a distance of about 90 miles from near the foot of the hills to its junction with the Ganges, without any damage being thus caused to the villages which are situated between the embankments and the river. The bridge over the Beas is amply sufficient to carry off any amount of discharge likely to be brought down, even supposing the river to be embanked up to the foot of the hills, so no fear need be entertained on this score. The average spill over the bank is apparently only 3·5 feet in depth (10 feet in the Hamíra and Ramídi), and the average height of the embankment will, therefore, be less than 6 feet.

Above Rúrah, the principal place where the river spills is near the village of Mali at the head of the Beyn jhils. There has been a considerable correspondence in the Punjab Public Works Department regarding the encroachment of the river at this point. All the officers who have visited the spot are unanimous in their opinion that some measures ought to be adopted to prevent any further encroachment, and to prevent the river cutting into the jhils.

The Superintending Engineer, 2nd Circle, Punjab, has recommended—

(*a*). The construction of a bund and spur at Mali, to throw the river again into its right channel.

(*b*). The raising of the road from Naushahra to Miáni, and thence to Rúrah.

(*c*). The construction of an embankment from the high land at Dhanoia along the Sawar nallah.

(*d*). The raising of the Bhatt ghát road as far as its junction with the Naushahra and Miáni road.

These propositions, the total cost of which is estimated at less than Rs. 80,000, are now before Government.

If the embankment is constructed from the Beas bridge to Rúrah, and the measures recommended by the Superintending Engineer are carried out, the spill from the river will be entirely shut out of the Beas valley, and the waterway to be provided through the Railway can, therefore, be reduced to an amount sufficient to discharge the maximum drainage of the West Beyn, &c., *viz.*, 108,000 cubic feet per second, with a small margin in case of breaches in the embankment. A provision for 120,000 cubic feet per second will probably be found amply sufficient. To pass this amount, a superficial area of 20,000 square feet will only be required, and a lineal waterway of 2,000 feet, with the present depth of 10 feet, which, however, as an *average* depth, may, probably be reduced with advantage, in which case, of course, a greater length of waterway will be required.

The Grand Trunk Road runs parallel to the Railway at a distance of about a quarter of a mile on the north or up-stream side along the whole width of the valley from Hamíra to near the Beas. When the road was first made, timber bridges were constructed over the different streams in the Beas Valley. The aggregate waterway provided was 6,313 superficial feet, excluding the West Beyn. These timber bridges, however, were subsequently removed, and causeways made with a waterway of 26,650 superficial feet, or upwards of four times the amount originally given, and on which was based the size of openings allowed for the Railway bridges. No corresponding increase was given to the latter, which therefore had to pass off in the same time a considerably larger amount of water than originally calculated for; as formerly, the Grand Trunk Road acted to a greater extent as a protective bund, which unless overtopped, only allowed a comparatively limited quantity of water to pass through. Since the construction of the causeways the Grand Trunk Road can no longer be looked upon as a protective embankment to the Railway; and a proposition brought forward that the causeways should be built up as weirs, I look upon as a probable source of injury, and not a benefit, either to the railway, the road, or the villages situated above it.

It is obvious that some mutual arrangement should be come to between the Road and Railway authorities as to the waterway to be given, and the position to be assigned to the bridges and causeways.

Note by COL. J. G. MEDLEY, R.E., *on Waterways required in the East Beas Valley, Scinde, Punjab and Delhi Railway.*

Dated Lahore, 11th December 1878.

The bridges on the Scinde, Punjab and Delhi Railway in the East Beas Valley were practically destroyed by the floods of August last, and the line broken for a length of six miles, as already reported to Government. It becomes therefore necessary to decide on what steps should be taken to restore permanent communication in time before the next rainy season.

Major Forbes' Note attached shows that the eight streams concerned may practically be considered as three drainage lines. Of these, the first two, comprising five bridges (of which four were destroyed), failed, not from deficiency of waterway as required by the area of their catchment basins, but solely in consequence of the spill over the east bank of the Beas.

The third drainage, comprising three bridges (whereof two were destroyed), was decidedly deficient in waterway, which must here be considerably increased.

With regard to the river spill, Major Forbes recommends the construction of an embankment along the east bank of the river from the railway bridge to a point 16 miles higher up, and estimates that its average height will not exceed six feet. If so, its cost should hardly exceed Rs. 50,000, as I do not think that any stone facing would be necessary, and there can, I think, be no question that its construction would be a great boon to the cultivators along the bank who suffered severely during the late inundation.

Above these 16 miles another embankment or embanked road has already been proposed by the local Public Works authorities, and estimates for it, to the amount of Rs. 80,000, are now, it is believed, before Government. This will be so far an advantage to the Railway that it will shut out the spill now entering the West Beyn drainage, and I should think it quite fair for the Railway to pay a portion of its cost.

If these river embankments are made, a length of 2,500 feet only of bridging will be required for the whole valley on the railway, in order to provide the waterway due to a maximum rainfall.

If these embankments are *not* made (or *until* they are made), an additional 1,000 lineal feet will be required to pass the river spill, or 3,500 feet altogether. The cost of the additional 1,000 feet of viaduct will amount to about one lakh, while the full Railway share of the river embankments will probably cost as much; but there can be no question that it will be better to shut out the spill if possible.

The discussion of this embankment scheme will, however, take time; other interests are involved besides those of the Railway, and other parties have to be consulted before action can be taken. The Railway cannot *depend* on the embankment being made before next floods, and, as Consulting Engineer, I have to decide *at once* on what should be done in order to maintain communication during next floods.

As above observed, we require 2,500 lineal feet of bridging, whether the embankments are made or not; but, as it will not be safe to make this unless we can also provide for the river spill, I recommend that this shall meanwhile be temporarily provided for by flood gaps between the bridges. The total discharge due to this flood spill, as calculated by Major Forbes, is 60,000 cubic feet per second,* for which 20,000 square feet of flood opening must be provided. Of this, 17,000 square feet must be given to the line between the Mandorah and Ramídi, the balance being given to the West Beyn.

Should we again have a flood similar to last year, the traffic will be stopped during the passage of the flood waters down the gaps, and some damage will be done to the banks, but that is the worst that should happen.

The flood gaps should have descents not exceeding 1 in 100, and the railway banks need only be cut down below the flood line sufficiently low to give the required area of flood passage. I see no necessity for artificial protection to the slopes and bottoms further than the usual ballasting, as the arrangement is only presumed to be a temporary one.

Now as to the bridging to be provided at the several streams—

The Fattuchak bridge remains uninjured or nearly so, and Major Forbes shows that there is a superfluity of waterway provided here. No further addition will therefore be necessary.

The next bridge, the Mandorah, has been destroyed; it had one 60 feet girder, and one more may perhaps be added, though not absolutely necessary at this point.

The next bridge, the Hambowál, has also been destroyed; it had 102 feet clear waterway, and this might be doubled, as this bridge, the last and the next would have to provide for any spill from the Beas caused by any breach in the river embankment.

These three bridges crossing the first drainage will thus provide 433

* *Note*—*i.e.*, that was the amount of last season's flood, which may of course be higher another year.

lineal feet, or 3,654 superficial feet of waterway for a rain discharge of 6,000 cubic feet, which might be considerably increased by spill from the river without doing harm, though this spill will be separately provided for by the flood gap.

The next bridge (over the Ramídi nallah) had 101 feet clear waterway, and might also be doubled for the same reason as the last.

The next bridge (over the Ramídi itself) had 202 feet waterway, and might be increased to 303, as Major Forbes' Note shows that the Ramídi drainage, though just sufficient, has nothing to spare.

There will be provision made, as above noted, for a flood gap of 17,000 superficial feet between the Mandorah and this last bridge.

These two bridges crossing the second drainage will thus provide 505 lineal feet, or about 5,050 superficial feet of waterway for a rain discharge of 21,000 cubic feet; any further increase to this discharge, due to river spill, being provided for by the flood gaps above-mentioned.

We now come to the third or West Beyn drainage.

The West Beyn itself had 150 feet clear waterway; the Chatar Singh, which stood, and which belongs to the same drainage, has 96 feet; and the Hamíra, also belonging to the same drainage, had 193 feet, making a total of 439 lineal feet, or about 4,500 square feet to pass a maximum rain discharge of 81,000 cubic feet clearly insufficient. An addition of some 9,000 superficial feet is evidently necessary. I would double the waterway of the West Beyn itself, add 50 feet to the Hamíra, and then add 1,000 lineal feet of flood openings between the two bridges, in the same manner that I have already proposed for the East Beyn. If this cannot be done in time, I would substitute an equivalent flood gap, for which I think there is room.

The total length of waterway to be thus provided in the East Beas khádir will thus be 2,577 feet in a length of 7½ miles, or about 1-15th of the whole, certainly not an extravagant amount in such a valley.

I have now to remark on the influence of the Grand Trunk Road embankment as tending to aggravate the results of these floods, owing to its position on the up-stream side of the line.

Major Forbes is of opinion that, as the road embankment was generally topped by the floods along its whole length in this valley, the mischief done by the pent up waters being let on to the railway through the flood gaps must have been less than Mr. Stone supposes, as the road virtually became a drowned weir; but that the destruction of the West Beyn railway bridge was clearly due to the breach of the road embankment close to the road bridge, by which a torrent of water was suddenly poured on to the railway bank. The road bank, however, *before* it was topped by the advancing flood, must have poured torrents of water on to the railway through the flood gaps, and must, I think, have caused great damage to the latter.

It can now answer no practical purpose to revive any discussion as to past proceedings in this matter, but there can be no question that, situated as these two embankments are, action should be taken conjointly.

The railway will be safe from any harm caused by ponding up any future flood against the road bank, if the metalled gaps in the latter are made with long gentle slopes, so that the water may not be let through with a rush, and there will, I presume, be no objection to this arrangement on the part of the Road Engineers. *But unless this is done, there will be distinct danger to the railway bridges;* and I would therefore beg that the Punjab Government will direct the Superintending Engineer to place himself in communication, without loss of time, on this subject, with the Chief Engineer, Scinde, Punjab and Delhi Railway, informing him exactly of what is proposed, any difference of opinion being *immediately* referred for decision of higher authority.

As the metalled gaps in the Grand Trunk Road are meant to provide for the river spill, then they would not affect the safety of the railway, if or when that spill was shut out by the embankments above-mentioned, —in fact they would not be necessary.

But *until* that is the case, they are unquestionably a source of danger to the railway. Now, as it is evidently undesirable to provide bridging on the railway that may not be required if the spill can be shut out, any roadway gaps that are considered essential for the safety of the road, must be met by corresponding gaps in the railway as a temporary arrangement.

If it is found impracticable to make the embankments in order to shut out the spill, then the temporary gaps left in the railway must be replaced by a regular viaduct.

The Chief Engineer should of course lose no time in submitting regular plans and estimates for formal sanction. But meanwhile it is necessary that I should give Government some idea of the probable cost of the work.

In the first place it must be stated that the girders washed away last season are hopelessly irrecoverable; they are buried in deep water, and the only one that has been dragged out has cost a good deal more than it is worth.

The masonry work (piers and abutments on well foundations) is also practically destroyed, and the bridges have to be estimated for as entirely new works.

The Chief Engineer will state his proposals in detail hereafter. I have discussed the subject with him, and drawn his attention to the cost of similar kind of work lately executed on this line, which I think is higher than it ought to be.

Considering that a bridge like that over the Jhelum on the Punjab Northern State Railway was made for Rs. 355 per lineal foot of waterway, and that over the Chenab, with wells 70 feet deep, was made for Rs. 550, I think that spans under 100 feet, on well piers 40 feet deep, should certainly not exceed Rs. 400 per running foot as a maximum.

The Chief Engineer estimates flood openings of small girders with masonry piers, floorings and drop walls at under Rs. 100 per foot of waterway.

The cost, therefore, of the 1,372 feet of bridging now to be provided should certainly not exceed 5½ lakhs.

This Note is now sent on to Mr. Stone, with Major Forbes' Note, for any remarks he may desire to make.

The Notes will then be printed and copies sent to the Punjab Government and Government of India.

Meanwhile, as there is no time to spare, the Chief Engineer, Scinde, Punjab and Delhi Railway can, if the views expressed meet with his concurrence, proceed with the work to the extent indicated above.

As it is uncertain whether the work can be completed before next season, it is evidently necessary first to make provision for any possible early floods by means of proper gaps in the bank, so that any bridges under construction may not be risked.

No. 262R, dated 15th January 1879.

From—*The Government of India, P. W. Department.*

To—*Consulting Engineeer to the Govt. of India for Guaranteed Railways, Lahore.*

I am directed to acknowledge the receipt of the printed Notes drawn up by yourself and Major Forbes on the subject of the waterways required for the East Beyn and East Beas Valleys to prevent the recurrence of breaches on the Scinde, Punjab and Delhi Railway in the East Beas Valley, and to request that Mr. Stone, the Company's Chief Engineer, may be informed that the Government of India will be glad to receive as early as possible an expression of his views on the proposals contained therein.

Dated 18th December 1878.

From—C. Stone, Esq., *Chief Engineer, Scinde, Punjab and Delhi Railway.*

To—*Consulting Engineer to the Govt. of India for Guaranteed Railways, Lahore.*

I have the honor to acknowledge your No. 2497 of 5th instant, giving cover to Major Forbes' and your notes on flood damages of 19th and 20th August 1878 in the East Beyn Valley.

Having discussed the main points and the calculations with yourself and Major Forbes on the 30th November, my remarks need not be very voluminous, the chief question being as to the length and description of bridging to be used across the valley.

It will be advisable if I take your notes *seriatim*—

Paras. 1 *and* 2—Need no remarks.

Para. 3.—The calculations of Major Forbes show that the total discharge to be provided for is 85,000 cubic feet per second, allowing for a velocity of 6 feet per second.

Paras. 4 *and* 5—Give the amount of lineal feet of waterway required for the discharge of the 85,000 cubic feet. The manner of providing for this will be found tabulated at the end.

Para. 6.—I admit (as a general principle) the objections made to widen the bridging of the main channel beyond the alteration of having but one pier instead of two, with the defined banks of the East Beyn, except that the river by the late floods has been widened out at the bridge by scour behind each abutment, and I am of opinion that it would be better to span these gaps by the two extra 110 feet girders (making the old abutment piers) than putting them away from the main bridge. The channel of the river is so well defined and deep, that any silt deposited in moderate or slack flood would be cleared away in strong flood.

Para. 7.—I approve of giving the additional flood openings with 30 feet girders (or a portion of these additional flood openings might be spanned by 16 feet girders made up in the Engineers' workshops), with brick piers on ordinary foundations, the same as at the 40 feet girder bridge, and double 20 feet girder bridge in the same valley, a little westward of the main bridge, unless upon excavating to put in the foundations the soil is found to be unsuitable at any point, when I should use well foundations in lieu of brick foundations on concrete.

Paras. 8 *to* 15.—Major Forbes is clearly of opinion that the provision for the discharge of 85,000 cubic feet is sufficient, and I should be disposed to support his opinion. But the destruction has been so great and the probabilities (from the evident increase of rainfall in the Jullundur and Hoshiárpur Districts) of even a greater rush than 1878, that it would be better to err on the right side and give an increase than subject the line to further disasters. Had the line been a greater distance from the hills, I certainly would not have approved of an increase beyond that proposed by Major Forbes. But from its nearness to the lower range of hills, and crossing this contracted and deep valley at right angles, I should prefer giving an increase beyond that proposed as necessary (for the 85,000 cubic feet) by Major Forbes. Seeing this immediately after the destruction of the bridge, and whilst the flood was partly on, I remarked that it looked to require to be bridged with as much waterway as is given at the Márkandá. But, as you observe that you will endeavour to obtain further records which might strengthen your opinion, the length of additional flood openings beyond the two 110 feet and the 5·30 feet can be accepted, and the work proceeded with pending your further enquiries. The objection to the postponement of the question is, that having to telegraph to England for the girders, the delay might very seriously retard the completion of the work, should it be decided to carry out your proposal of 32·30 feet spans.

Para. 16.—At the time I suggested the 30 feet girders on raking screw piles, and 16 feet on smaller vertical piles, I was not aware of a similar principle having been tried upon the Punjab Northern, and found not to answer satisfactorily; and I should certainly prefer using masonry piers and 30 feet girders only for this contracted and deep valley; the smaller spans I suggested were for the long low flood openings between the bridges in the Beas or Western Beyn Valley.

If the shorter length of bridging of five spans of 30 feet only is used, then I certainly would adopt the plan of backing up the last pier with stone and using it as an abutment; but if a long length as proposed by you is adopted, I would prefer completing the viaduct with the usual wing-walls. A further and more important reason for adopting masonry piers is, that in estimating for the alteration after making working drawings, I find that the 30 feet girders on masonry piers, it is cheaper than the screw pile arrangement.

The approximate cost per foot run of the alternative proposals is already before you.

I will submit, at the earliest possible date (after the full amount of waterway is settled), detail estimates of the cost of the whole works for the East Beyn Valley.

Amount of new bridging decided upon at present—

			Lin. ft.
East Beyn River, two girders of 136 feet,	... ...	=	272
" " " of 110 "	... ...	=	220
" " five spans of 30 "	... ...	=	150
Total of new work,	...	=	642

And for this I would ask for immediate sanction, or rather I would say for the two 110 feet to be removed from the Sutlej Bridge and five spans of 30 feet girders, and the earliest possible decision of the further increase either with 30 feet or 16 feet girder; but, as before observed, I would prefer the 30 feet girder for this valley.

Having discussed upon the ground and in subsequent interviews with the Consulting Engineer and Major Forbes the general proposals, and practically accepting the plans to be adopted to endeavour to prevent a repetition of the disaster in the Beas Valley, it will be unnecessary for me to do more than make a few remarks upon the proposals for shutting out the spill of the Beas River, the additional waterways, and the description of girders to be employed for the construction of the bridges and flood openings. I will take the Notes of both officers conjointly.

The Consulting Engineer, it will be observed, in page 376 of his Notes, endorses my opinion already recorded, that it would be useless to further discuss the past, but that joint action should be taken with the Superintending Engineer of the Grand Trunk Road and myself as to what had best be done at the Grand Trunk Road, and in this latter point I fully agree, and trust that such joint action may be taken early, in order that I may know at what points I should place some of the additional flood openings, as well as to know if the Grand Trunk Road Engineers will reduce the inclination of the slopes at the causeways; this I consider an important point to save the great rush, which under present circumstances, come down upon the line.

Embankment proposed for shutting out the spill of the River Beas.—I have had no experience in damming out the spill of a large river; but both the Consulting Engineer and Major Forbes having given instances of longer embankments than the one proposed of 16 miles having been carried out, and with success, I would certainly accept the experiment in this case, more especially as my views throughout have been to endeavour to keep the river in its present course, as it will be remembered that my original views with this object were to raise the causeways and endeavour to bring the body of water passing through the Grand Trunk Road back to its normal or original condition when the line was first constructed—(*vide* my report on flood damages, 1875, dated Lahore, 4th November 1875). It was suggested through the Consulting Engineer, in the beginning of last year, that the upper part of the river might be shut out by a bund above head of the West Beyn jhils, but I did not consider it would be of any practicable benefit to shut it out for a short distance some 60 miles above the line of railway, as it would spill in again immediately it had passed the end of the bund or groyne. But I am of opinion that this proposal would now be of advantage in connection with the proposed 16 miles of embankment—the upper bund to shut out the spill of the river into the West Beyn drainage, and the embankment to shut out the spill from the Hambowál and Mandorah drainage, that is to say, if full waterway is not given at the railway to carry off both the rainfall and river spill.

The average height of the water spilling over the east bank of the

Beas River, as shown by the section taken by this office in December 1875 for 14 miles above the bridge, averages 3·5 feet in depth, and it is proposed to throw up an embankment of six feet in height; this would give 2·5 feet above flood; this, for a new embankment (supposing it to be carried out), I do not consider would be sufficient; every precaution must be taken to prevent a breach, and with new earthwork there would be a considerable amount of settlement; and there is no reason to conclude that the 3·5 feet would be the maximum of flood when the river is shut out from the valley over a large area of country by an embankment of 16 miles in length, in addition to the proposed embanked roads referred to in Major Forbes' Notes, page 371 (*a*), (*b*), (*c*), (*d*), and I would prefer that the embankment be thrown up seven feet in height, or otherwise met by very long slopes towards the river, for there is not only the certainty of considerable settlement of the new earth during the floods, but, as the spill of the river would run parallel with the embankment, there would, I fear, be a considerable amount of scour along the toe of the slope.

Another ground of objection will, I have no doubt, be brought forward against this long embankment by vested interests of Zemindars and the Kapurthala State through shutting out the spill of the river through the channels (except the West Beyn) which, I believe, are used for irrigation purposes; such objection was, I know, raised by the Kapurthala authorities when I proposed to raise the causeways in the Grand Trunk Road, for, excepting the West Beyn, the remaining seven channels are not affected to any appreciable extent by the rise of the River Beas until it tops the east bank. With the West Beyn this is different, the large jhils being formerly the main channel of the river the water filters in, and since the encroachment of the river, as far as my observation has gone, occurs in a much greater degree; for example, on the 5th of November 1878, the Beas River rose 17 inches; the West Beyn at the same time also rose 17 inches; again on the 11th instant, the Beas rose 7 inches, and an exactly corresponding rise took place in the West Beyn.

Length of waterway to be provided across the Beas Valley.—The calculation for the length of bridging is 2,500 lineal feet if the embankment is made, and 3,500 feet if the embankment is not made, but it is to me clear, even if the unanimous opinion of all interested should be in favor of the embankment, and such opinion arrived at, at an early date, the embankment could not be thrown up in one season in time to meet the ensuing year's floods, and with the chances of the breaching of the embankment (assuming that it could be thrown up in time) during its first season or two, or until well consolidated. I am of opinion that the full length of bridging of 3,500 feet should be provided, or as much of it as can possibly be got in by say the 30th of June next. Two months of the best working season have passed, and I can foresee that it will only be by working early and late and strong gangs of workmen, and extensive European supervision, that such an amount of bridging as 3,500 feet can be got in by the 30th of June next. But I am aware that the subject was of such serious importance that it became necessary to give it the most careful attention.

Description of the proposed bridges and flood openings.—The proposals are to span the West Beyn and the remaining five distinct openings or nallahs with girders of 110 feet and 60 feet girders, and for the viaduct (or escapes if I may so term it) of 30 feet and 16 feet girders, in accordance with designs already laid before the Consulting Engineer. The large girders to be on well pier foundations, and the smaller upon brick foundations, drop walls and floorings.

Since submitting the proposed designs for the 30 feet and 16 feet girders (the latter being the cheapest, and costing about Rs. 100 per foot run), I remembered a cheaper description of girder that may with advantage be used, composed of rails only, and giving a span of 8 feet 5 inches; this description of girder I used to some extent on the lower section of the Mooltan line some 16 years ago, and they have stood remarkably well; the cost will not exceed Rs. 20 to 30 per foot run, depending upon the height of the masonry, and it will be for the Consulting Engineer to state if he approves of the design (which is herewith sent), and how much shall be put in between each large or main bridge; and it is this latter description of flood escape that I would propose to use, instead of the suggestion of running down on to natural surface,—a responsibility which I should not like to commit myself to for several grave and important reasons—1*st*, as the valley is liable to be flooded at times from the 1st of July even up to as late as the end of September, the line might be breached several times, which on each occasion would cause the most serious inconvenience to traffic; 2*nd*, if breaches occurred, there would be considerable difficulty in obtaining earth or ballast in sufficient quantities to at once make up the road, and in all probability, as soon as done, it would be again washed away; *3rd*, the liability to accident, a road might to all appearance be good, but from the treacherous nature of the soil it might be so saturated or undermined as to give way whilst a train was crossing, and cause destruction to life and property, and even supposing it had not breached, if under water, no train could possibly be permitted to pass over until the flood had fully subsided and the line minutely examined; with the rail girders on masonry as shown on accompanying sketch, there would be no such risk.

Comparative cost of the works on Scinde, Punjab and Delhi and Punjab Northern State Railways.—The Consulting Engineer remarks in page 377 that the cost of works lately executed on this line is higher than it ought to be, and also in the same page points out that bridges on the Northern State had cost considerably less; I do not for a moment doubt this, but the cases are far from being parallel. The cost quoted of the Punjab Northern State bridging is for works executed upon an unopened line with plant and every available means at hand to carry out the work provided for on a large scale. The work of reconstruction was in the case of the Scinde, Punjab and Delhi on the open line—diversions had to be put in and scoured gaps filled up, or the existing embankment had to be removed if a new work; brick kilns had to be erected, and plant provided, specially for the single work; trains with material have to be run to suit traffic trains, and it often happens that only one train per day could be got out to the works; further, working against time, and often with supervision by the best Inspectors that could be obtained at the time, and these men on temporary works do not take that interest in getting a good day's work done that would be the case by permanent men.

Sanction for the commencement of the works.—Having generally accepted the proposals in the notes under reply, I have, in accordance with page 377 of Government Consulting Engineer's Notes, given instructions to proceed with so much of the bridgework as can be at once commenced, and in anticipation of such requirements, I have had a large number of well curbs made, and some 12 to 15 lakhs of bricks burnt. Every exertion will be made to push the works, its completion in time largely depending upon the obtaining of the girders, and whether we have a dry or wet cold season.

No. 643R, dated 10th February 1879.

From—*The Government of India, P. W. Department.*
To—*Consulting Engineer to the Govt. of India for Guaranteed Railways, Lahore.*

I am directed to acknowledge the receipt of your letter No. 84, dated the 14th January 1879, forwarding copy of a Note by Mr. C. Stone, Chief Engineer, Scinde, Punjab and Delhi Railway Company, containing his views on the Notes prepared by Major Forbes and yourself on the waterways required in the East Beyn and East Beas Valleys for the protection of the Railway.

In reply, I am to refer to Public Works Department No. 555R, dated 4th February 1879, forwarding a copy of Public Works Department No. 554R of the same date to the address of the Punjab Government, relative to the construction of the 16 miles of embankment required from the Beas bridge to the village of Rurah, the spur at Mali, the short embankment along the Sawan nallah, and the repairs to the Grand Trunk Road causeways. These points having been decided, I am directed to inform you that the Government of India approves of Mr. Stone's proposal to provide 642 lineal feet of waterway in the East Beyn Valley, and of your proposal (page 375 of your Note) to provide 2,577 lineal feet waterway in the East Beas khadir. Estimates should be submitted at an early date.

Second Note by COL. J. G. MEDLEY, R.E., *on Waterways required for the East Beas and East Beyn Valleys, Scinde, Punjab and Delhi Railway.*

Dated Lahore, 27th February 1879.

In continuation of my former Note on this subject, and of Mr. Stone's Note following Major Forbes' and my own, I have now received the Chief Engineer's specific proposals in detail, and have again been over the ground with him to examine the works in progress.

With regard to the East Beas Valley, Mr. Stone has virtually accepted our calculations and recommendations as to the amount of waterway to be provided, and his proposals in detail are as follows:—

The Fattuchak bridge will remain unaltered, except as regards the reconstruction of the wing-walls, which have been cracked.

The Mandorah will have two 60 feet girders, or one more than it had before, as recommended.

The Hambowál will have four 60 feet girders = 220 feet clear waterway, instead of 102 feet as before.

The Ramídi nallah the same, 220 feet.

The Ramídi river, three 110 feet girders = 303 feet clear waterway, instead of 202 feet as before, as recommended.

For the flood gap of 17,000 superficial feet, proposed in page 375 of my Note, between the Mandorah and Ramídi bridges, the Chief Engineer proposes, as shown in the section, one between the Mandorah and Hambowál, 2,970 feet long; another between the Hambowál and Ramídi nallah, 1,089 feet long; and another between the Ramídi nallah and Ramídi, 1,320 feet long. As these would have an available average depth of five feet below the line of last year's floods, we should have a superficial area of 27,000 feet, instead of 17,000 feet, or the flood of last year would have passed at a depth of about three feet, which is certainly all that should be allowed.

These gaps have been fixed with reference to the grades down to them not exceeding 1 in 500, and the Chief Engineer proposes, as in his first Note, to span them by rail girders supported on masonry pillars 8½ feet apart, having a continuous flooring of block kankar one foot below the natural surface, and protected by apron walls front and rear. Mr. Stone reckons that this style of construction will not exceed Rs. 25 per foot run, and that it is by far the cheapest unit of viaduct that he can devise.

From my former Note it will be observed that these flood gaps were only proposed as a temporary expedient, pending the construction of the embankment for shutting out the river spill; that I did not propose bridging them; and that I was prepared to face the possibility of a temporary stoppage of traffic in case of another extraordinary flood. The Chief Engineer naturally wishes to avoid this if possible, and if it can be done at a reasonable cost, it certainly should be done. I am quite sure that so long as the river spill is not shut out, the large bridges will not be safe without these gaps, unless, indeed, a continuous viaduct is made across the whole valley. In that case something might be saved on the larger bridges, which would not then require to be so high, but their channels would still have to be crossed by large spans and piers on well foundations; and as, even were there no bank at all across the valley to head up the flood, there might still be a rush down these nallahs, it is not advisable to lower them too much.

Whatever may be the ultimate decision come to as to the construction of the embankment along the river in order to shut out the spill, it seems tolerably certain that it can hardly be completed prior to next floods, while the loss to the railway, by a break in the traffic of even a few days, would certainly exceed the cost of bridging them, as proposed by the Chief Engineer.

After full consideration of the detailed drawings and discussion with Mr. Stone and Major Forbes, we have come to the conclusion that the Chief Engineer's proposals may be accepted with certain additions to the flooring, and that the work may be looked on as permanent, while, even if breached, the cost of repair will be small, and there will be no difficulty in adding to it hereafter if required. I have therefore authorized the work to be proceeded with. If the river embankment should eventually be made, it will be a great additional protection to the railway, while the whole of the ironwork of the viaduct over the gaps could at any time be utilized elsewhere if no longer required.

[Since writing the above, I have heard that orders have been given to construct the embankment. To what extent the work can be completed before next floods is at present uncertain; but I have asked Mr. Stone to postpone work on the gaps to the latest safe period, until we know definitely what can be done. Under any circumstances, so far as the railway is concerned, I think the embankment should be made, as even the gaps will only provide for a spill similar to that of last year, and we may get a much larger one if the embankment is *not* made. I should hope that there will be time this season, at any rate, to construct the spur at Máli, recommended by Major Forbes, to prevent further action of the river towards the head of the West Beyn, and at any rate to fill in the local depressions on the line of embankment, by earthen bunds faced with brushwood, or stone if necessary].

For the West Beyn drainage, the Chief Engineer proposes four 110 feet girders = 404 feet clear waterway at the West Beyn itself, and 320 feet at the Chatar Singh and Hamíra, or 724 feet altogether, instead of 439 feet as before, which would pass nearly 50,000 cubic feet of drainage per second. For the 1000 lineal feet of flood opening, which I proposed in addition to the above, the Chief Engineer proposes two flood gaps similar to the above. In the case of the West Beyn, the calculations show that the above length of viaduct is actually required for the rain discharge, so that it would not be a temporary expedient (like the other gaps) even if the river spill is hereafter shut out. If, therefore, the time will admit of it, a viaduct of the above length should be added as proposed for the East Beyn; if not, I would accept the Chief Engineer's proposals for gaps similar to the others, at any rate for the present, the two gaps proposed giving 1,419 lineal feet.

The above will give the full amount of waterway as calculated by Major Forbes, which I was at first disposed to accept; but after full consideration, as in the case of the East Beyn, I think it right to recommend some addition. The case of the West Beyn is so far more favourable that this bridge is 10 or 12 miles further from the hills than that over the East Beyn; but, on the other hand, its catchment basin is more compact, and it is liable to have an increase over that due to a maximum rainfall by some spill from the Beas in its upper portion, and bearing that in mind I am not inclined to reduce the value of the coefficient in the Dickens' formula below that for the East Beyn. This would give a discharge of 107,250 cubic feet, or some 26,000 in excess of Major Forbes' calculations, and an addition of some 400 feet to the length of viaduct required, or double that length of flood opening. Unfortunately, this cannot, however, be given in the flood gaps, as there is no room, and it will be necessary, therefore, to complete at least the above length of regular viaduct, *i. e.*, 400 feet out of the 1,000 feet shown to be required as above.

With reference to this additional waterway which I have asked for in the case of both the East and West Beyn, I may state that I sent the printed Notes on the above subject to General Sir A. Taylor for his opinion previous to his departure from India, and that he fully supported my view not to reduce the full value of the Dickens' coefficient over the whole drainage area, as we had no proof that the last year's flood was a maximum.

It appears, however, on enquiry from the Chief Engineer, that he will not be able to complete the full amount I have asked for during the present season; there will be just enough girders available to complete half the extra quantity in either case; and as Major Forbes thinks I have given a super-abundance, and his opinion is doubtless entitled to great weight, I should propose to compromise our difference to this extent, and will ask the Chief Engineer to estimate accordingly.

The additional 200 feet thus required for the West Beyn can be given by 14 of the girder openings as proposed by Chief Engineer for the East Beyn, and can be added on each side of the two gaps with floorings arranged on the same principle of construction as already discussed and approved in the case of the small rail girders, but with some extension on the down-stream side.

The Chief Engineer has given his reasons in the Memo. attached for throwing the Chatar Singh and Hamíra bridges into one. This renders it all the more imperative that the corresponding causeways in the trunk road should be sloped down as already recommended, and I trust that immediate orders on this point will at once be given by the Punjab Government.

The total waterway to be thus provided in the East Beas Valley will thus be—

	Lin. feet.
Fattuchak, ...	109
Mandorah, ...	110
Hambowál, ...	220
Ramídi nallah, ...	220
„ river, ...	303
West Beyn, ...	404
Chatar Singh and Hamíra, ...	320
14 feet girder openings flanking the two gaps, ...	196
	1,882

Besides the following flood gaps to be spanned by rail girders:—

	Lin. feet.
No. 1 (beginning on west side), ...	2,970
„ 2 „ „	1,089
„ 3 „ „	1,353
„ 4 „ „	627
„ 5 „ „	792
	6,831

Nos. 1, 2 and 3 gaps would not (as explained in my former Note) be required if we could be certain that the river spill would be shut out by the proposed embankment, and work on these three gaps should be postponed until it is clearly ascertained what we can depend upon in this respect, which I hope will be settled in a few days.

With regard to Nos. 4 and 5 gaps, the case is different; they must be made in any case, as there is a clear deficiency of waterway for the West Beyn drainage irrespective of the river spill, and they are only now proposed as more economical than ordinary girder openings on higher piers, and because the more expensive work cannot be completed within the limited time at disposal.

East Beyn.

I now pass on to the East Beyn Valley, the proposals as to which have also been accepted by the Chief Engineer. The bridge over the main channel will, as recommended, comprise two openings of 136 feet, and two of 110 feet. This will be flanked by three girder openings of 30 feet on each side, and these, with the small separate bridges in the same valley, will complete the waterway as estimated by Major Forbes and sanctioned by Government.

But, as explained in my former Note, I do not consider that sufficient provision will thus be made. I asked for 800 feet more of flood openings in addition to the above, but, for the reasons stated already in page 388, shall be satisfied if half that quantity is now given, and this, I trust, will be sanctioned.

A recent visit to the scene and further consideration of the violent character of the late flood, and of a further source of danger in the tortuous course of the channel just above the bridge, by which I have no doubt the water is heaped up and spilled over the bank, convinces me that it will only be prudent to add to the flood openings already provided, and Mr. Stone, agreeing with me, proposes to add 28 of the 16 feet girder openings, giving nearly 400 feet clear waterway, similar to the 14 openings above proposed for the West Beyn. These, like the others, will be on masonry piers, with flooring and drop walls.

The Engineer Department deserves credit for the satisfactory progress that has already been made with the work in both valleys; the only delay that is likely to occur is the non-arrival in time of the girders from England; but Mr. Stone will, I know, duly consider all arrangements that may in that case have to be made for temporary emergencies.

I have explained to the Chief Engineer, who, I believe, agrees with me, that I consider the gaps as indispensably necessary to the safety of the large bridges, and that if there is not time to bridge them as proposed, temporary piers must be provided, and no portion of them filled up.

Copy of this Note will now go to Chief Engineer, with a request that the work may be proceeded with as herein laid down; estimates being submitted as soon as possible.

Also that the sections received from him and now returned may be corrected accordingly, and re-submitted for the information of Government, to whom copy of this Note, when printed, will also be sent.

Note on the Indus Floods, with reference to the Indus Valley State Railway. BY MAJOR J. G. FORBES, R.E.

Dated Lahore, 20th February 1879.

The absence of sufficient reliable data makes it a peculiarly difficult matter to offer any opinion on the best method of dealing with the floods of the Indus. The facts, however, mentioned in the Flood Reports of 1875 and 1876, together with those noted during the flood of 1878, show that on the left bank of the river, between the confluence of the Chenab and the narrow pass at Bhakkar, there are four main or primary spills which cross the Railway near Naushahra, Mirpur, Ghotki and Sangi. On a map showing the original surveys made for the Railway, 15 or 18 years ago, these four spills are distinctly marked; thus denoting they are not casual, or secondary, spills like those mentioned in next paragraph; but that their positions may be looked upon as *comparatively* fixed, and not liable to any very sudden alteration.

Besides these four main spills, the Indus, like other rivers, floods over its banks, sometimes in one spot and sometimes in another, according to the set of the stream, and attacks the Railway at uncertain places between Kot Samaba and Rohri, along the whole of which distance (120 miles) the line is carried through the flooded tract.

Taking up the Index Map of the Indus Valley State Railway, we can see that from Mithankot to about 20 miles above Kusmore the country through which the Indus flows must have a steady fall from the hills to the Bahawalpur desert, as this is clearly evidenced by the trend of the hill streams, which flow perpendicularly towards the river on the right bank; and by the absence of inundation canals on that bank between Mithankot and Kusmore. That this slope is continued on the left bank is also shown by the course of the Bahawalpur canals, which, following the natural slope of the country, run roughly perpendicular to the stream of the river. When the Indus arrives at a short above Kusmore, it can be seen that the slope in the country at once changes. Instead of running down direct at right angles from one side only of the river, it spreads out diagonally on *both* sides like a fan, which is slightly squeezed on the right, but more opened out on the left. This then would lead us to expect that while the flood between Mithankot and Kusmore would come more directly on to the Railway, the number of primary spills would probably be less than from Kusmore downwards. This conclusion is borne out by the fact that in the upper portion there is only one main spill, *viz.*, at Naushahra; whereas in the lower portion of the river to Sukkur, which is about the same length as the upper, there are five, *viz.*, two on the right bank at Kusmore and Begari, and three on the left, at Mirpur, Ghotki and Sangi.

The construction of any long line of embankment will at once alter existing conditions. The practical effect of long embankments is to raise the high water mark, and to slightly increase the caving of banks;* thus inducing larger floods, not only at the primary and secondary points, but also the formation of spills at places not previously attacked.

An embankment has within the last few years been made for a length of 41 miles along the left bank of the Chenab, from the junction of the Sutlej to the confluence of the former river with the Indus. This embankment effectually protects the ground behind it; and also probably conduced last year to prevent the floods, as formerly, attacking the Railway above Kot Samaba. It is proposed to extend the embankment still further down the Indus; but if this is done, the increased volume, which is now expended in spill, will undoubtedly cause the river, which already has a great tendency to do so, from being above the natural level of the ground, to burst through its banks lower down in a greater number of spots, and with much more force than it now does. As it is utterly impracticable to construct continuous lines of embankments along the whole length of the Indus from Mithankot to the sea, it is evident that any extension of the Bahawalpur embankment will only save a small portion of country at the expense of a much larger area lower down; and that the more the embankment is extended, in a

* See page 17 of Report dated 18th January, 1875, of Commission of Engineers appointed to investigate and report on a plan for the reclamation of the basin of the Mississippi river, subject to inundation. This Commission was composed of Major-General Warren, U. S. E., President, Brigadier-General Abbot, U. S. E., Major Benyaurd, U. S. E., and Messrs. Sickels and Hébert, Members. The Report was submitted through Brigadier-General Humphreys, U. S. E., who stated that the views of the Commission met with his full concurrence

constantly increasing ratio will the country below be swamped, especially where the change of slope occurs near Kusmore. There can, therefore, I think, be no doubt that the Bahawalpur embankment should *not* be extended.

The accompanying table shows the height of flood levels, in 1878, along the Railway, from mile 150 to mile 220:—

Nearest Station.	*Mile.*	*R. L. of flood.*	*Fall per mile.*	
Kot Samaba ..	150	278·50		
Naushahra ..	160	273·00	·55	Average fall ·61 per mile.
	170	267·60	·54	
Sadikabad ..	180	260·90	·69	
	184	258·40	·62	
		———	....	AHMADWAH CANAL.
		255·30	·38	Probably affected by back-water from lower spill.
Walhar ..	190	253·00	·60	
Reti ..	200	247·00	·77	
	207	241·60 } Level.		
Khairpur ..	210	241·60		
Mirpur ..	220	238·00	·36	

Between Kot Samaba and Khairpur the line was breached in numerous places, especially between miles 154 and 178; but the greatest strain was from mile 165 to mile 166. A reference to the Flood Reports of 1876 will show that it was at these places also where the heavy burst of the upper or Naushahra flood was experienced. It will be noticed also, in the above table, that where the Ahmadwah Canal crosses the Railway, there is a sudden drop of three feet in the flood level, the water on the north side of the canal bank being 258·40, and that on the south 255·30. For the six miles below the canal the surface slope of the flood is only ·38 per mile, being probably affected by the back water of the secondary spill near Reti, against an average of ·61, for the 34 miles immediately above it; but in the next 10 miles it again resumes this normal slope. The sudden drop (which was also noticed in the flood of 1876, *vide* para. 10 of Executive Engineer, Reti Division's letter No. 1277, dated 8th September, 1876) and the alteration in, and eventual resumption of, the regular flood slope, shows that the canal kept the upper floods entirely distinct from those lower down. It would therefore apparently be advisable to take advantage of the circumstance, and still further strengthen the bank of the canal, if there is any fear of its being breached, so as *completely* to isolate the Naushahra from the lower floods; especially now that the thorough reconstruction of the Kusmore bund will throw more water on these spills. If free exit is given through the Railway to the upper floods, they will pass off by the old river-bed, which runs parallel to the line at a lower level, and be absorbed in the desert. I concur therefore in the recommendation that this portion of the line should be raised, and the waterways increased; but the amount recommended, *viz.*, 85 lineal feet per mile, is, I think, inadequate.

I have not sufficient data to show the actual amount discharged through the Railway last year, or the possible quantity of flood that might have to be provided for; but on the East Indian Railway, where it crosses the Sone floods, which have a discharge of 165,000 cubic feet per second on the left bank of the river, 296 lineal feet (2,871 superficial feet) of waterway per mile has been clearly proved to be insufficient. On the right bank, however, where the floods amount to 65,000 cubic feet per second, a waterway of 153 lineal feet (949 superficial feet) has been found effectually to discharge the spill. In the former case the average depth of water is 9·70 feet, and approaches with a velocity, due to a fall in the country, of two feet a mile; in the latter, the depth is 6·20 feet, and the slope about one foot per mile.

There is nearly as much uncertainty on the Sone as on the Indus, where the floods will first attack the Railway. The points of attack of the primary or main spills, which are almost invariably marked out by local depressions, are known; but floods do not always come down these main spills in force, the secondary spills, which generally in floods of any duration find their way into the depressions of the main spills, are often at first of as great violence as the main floods, and rush on the Railway at totally unexpected places. As long as the bank is not overtopped, and a sufficient aggregate amount of waterway is given in the flooded tract, the effect is that the water is ponded up for a greater length of time in local spots, and that greater work has to be performed by the flood openings lower down; all of which of course must be protected to withstand the extra scour that may be thus induced. In the Sone floods of 1876, on the East Indian Railway, there were three bridges on the left bank of the river, and two on the right, absolutely dry. In the former high floods of 1864 and 1867, these bridges had discharged very considerable amounts of water, but, on the other hand, waterways which had done no work in the former years were in 1876 running with a velocity of 14 feet and upwards.

The conditions of the right spills of the Sone approximate to the upper Indus floods; where, however, apparently the depth and slope are somewhat less, *i. e.*, the direct transverse slope from the river to the Railway is only about ·75 per mile. Allowing for differences, it would not be safe to accept less than 120 lineal feet average waterway per mile as a *minimum* on the Indus Valley Railway between Kot Samaba and Reti.

It is true that in addition to the 85 lineal feet per mile of waterway recommended, it is proposed that long paved causeways for the escape of heavy floods should be put in, thus evidently showing that more waterway is considered necessary. But this proposal is saddled with the proviso that it is only to be done if the causeways "can be constructed at reasonable cost, and that sites can be found where they would act with efficiency." With all due deference, I submit that the construction of these causeways will be interpreted as an open admission of the failure of the line as originally projected. The Indus Valley Railway was taken along its present alignment with the full knowledge that the floods would have to be combated, and I presume that no alteration has been made in the original intention of its being a permanent and not a simple fairweather line. Putting aside the obvious disadvantages, both public and private, which will be entailed by the detention of trains, and totally ignoring the comments which will be occasioned thereby, it appears to me that once we admit causeways, we admit weakness and invite disaster.

The question of expense was, I take for granted, fully considered by Government when it was determined to lead a railway through the flooded tract, which so palpably might easily have been avoided. After an expenditure of six millions, the difference is comparatively so trifling between putting in permanent and temporary openings, that I have no hesitation in recommending the former, especially as I believe they will be found cheaper in the end.

There remains the doubt about the site of these openings. In the conclusions of the Committee held at Sukkur on the 23rd November, 1878, the places where the flood attacks the Railway between Khairpur and Rohri have been accepted as fixed, judging by the fact that nothing more is apparently required than the filling in of holes below bridges. If the sites in this part of the line, which is more difficult to deal with than the upper, can thus be definitely accepted ; in the upper portion surely there cannot be such an absolute uncertainty as to preclude permanent openings being built, especially after the experience gained in, at least, three great floods. The existence of "depressions," "great depressions," "low ground," &c., is continually spoken of in the reports of different officers as places where the floods came down; in some cases the banks were breached, and in others the water was turned off laterally until it found vent in bridges or culverts lower down; the velocity through which was enormous, 18 or nearly 19 feet per second having been measured in one case. One certainly of these great depressions (the Madd Dhora, in the Ghotki Division) was entirely embanked across, and the spill which came down it completely shut off at the request of the Civil Officers. In 1876 the bank was breached, and 200 lineal feet of waterway put in, but other marked depressions may exist which still are embanked or inadequately provided with ventage. These facts would point to the conclusion that permanent sites can be obtained at once by extending the present flood waterways, and opening new ones, if necessary, at the "Dhunds," "Dhoras," and other well known localities where floods constantly come down or accumulate.

On the grounds above stated, I am of opinion that in lieu of 85 lineal feet waterway per mile, plus temporary flood gaps, it will be better at once to put in permanent waterways, aggregating at least 120 lineal feet per mile, not scattered about in small and danger provoking vents, but concentrated as much as possible in effectually large flood passages.

With reference to the lower part of the line, the effect of a practically continuous bund from Kusmore to Sukkur must be to raise the flood level, induce fresh sets, and increase the spill on the left bank. This of course could be counteracted by a parallel embankment; but the danger attendant to Sukkur and the villages below, as well as to the Railway between Sukkur and Larkana, would put this project out of the question. As it is, the Kusmore bund may appreciably increase the afflux already existing in high floods at the narrow pass at Sukkur. This amount of increase is easily capable of calculation, but the data to determine it have not, as far as I am aware, been collected yet. In a similar case on the Ganges near Rampur Bauleah, which was most carefully worked out two years ago (by Mr. A. J. Hughes, Executive Engineer, Irrigation Branch, Bengal) on extensive and very accurate surveys and levels, it was found, I think (I have not my notes to refer to) that the effect of an embankment 80 or 90 miles in length along one side of the river to shut out a spill of upwards of 200,000 cubic feet per second would probably be to raise the height of the flood two feet at the lower end of the embankment. Taking this as an approximate guide, and allowing roughly for the difference in the slopes, and number of curvatures, also for the lesser spill and length of embankment, it certainly would not be safe to accept less than one foot as the increased height of a maximum flood wave below Ghotki, and an increase of some inches in the afflux at the pass. To mitigate the effect of this possible increase then, the spill must be passed off through the Railway as quickly as possible; and if this is done effectually, I see no reason why the afflux at Sukkur should not remain unaltered.

Referring back to the table shown in page 393, it will be seen that from mile 190 to mile 200 the flood surface is still ·60 per mile, or the same as in the 34 miles above the Ahmadwah, but in the next seven miles it is suddenly increased to ·77; it then remains perfectly level for three miles to Khairpur, and in the next 10 miles to Mirpur the slope is only ·36 per mile. The section does not extend below this point.

The cause of the surface level being horizontal has been ascribed to the large amount of cultivation near Khairpur, but this can scarcely account for it; nor does it afford a key to the reason why the slope should be suddenly increased from Reti to near Khairpur, and again very materially reduced below. An easier explanation will possibly be found if we remember that just above Reti the junction takes place between the perpendicular and diagonal slopes from the river; near Khairpur the Railway begins to curve round, and for the three miles where the flood surface is level, is probably nearly parallel to the edge of the fan which spreads out from its apex above Kusmore; from Khairpur to Mirpur the line probably does not follow the circumference, but is slightly inclined upwards to it, hence the alteration in the flood levels.

This, combined with the fact that at Reti the distinctive flood tract is entered on boats (used to ply from Reti to Sukkur over the inundated ground), and that it is here that the large and well defined "Dhunds" commence to be more marked, would signify that any alteration in the regimen of the river near Kusmore (especially noting the bend due south of Kusmore from which a primary spill occurs) will be peculiarly felt below Reti and near Mirpur.

At present the average amount of waterway allowed between Reti and Sukkur is 190 lineal feet per mile. In the section between Reti and Sarhad, from mile 200 to mile 230, I would strongly advocate a further extension so as to bring up the amount to *at least* 250 lineal feet per mile, as much as possible in large flood openings, notably in the vicinity of Mirpur. Between Sarhad and Rohri, or from mile 230 to mile 270, we know there are at present two main spills, besides many secondary ones, the numbers and effect of which will in time be increased by the action of the Kusmore bund. Taking this into account, as well as the present inefficiency of the ventage given, it is evident that the waterways in this section must also be materially increased. Probably they will have to be brought up to a *minimum* of 300 lineal feet per mile—an amount which is not sufficient to pass off the left Sone floods (page 394) without a considerable heading up. Besides the large opening which will be required for the Ghotki spill (unless there is any fear of the river breaking across the line there), a very large increase will have to be made at Sangi; judging from the fact that the waterway already existing there was evidently greatly too small for the flood of last year, as below every one of the five large bridges near the station, enormous holes extending to 40 and 50 feet in depth were formed.

It will be seen that the total amount of waterway that probably is required, at present in the 120 miles of flooded country through which the Indus Valley Railway is taken on the left bank of the river, is 25,500 lineal feet, or very nearly 5 miles, *viz.*:—

						Feet.
From Kot Samaba to Reti,	50 miles,	@	120	feet per mile,		6,000
" Reti to Sarhad,	30 "	"	250	"	"	7,500
" Sarhad to Rohri,	40 "	"	300	"	"	12,000
Total, ..	120					25,500

or about 4 per cent. of ventage on the length of line between Kot Samaba and Rohri—an amount which cannot be considered excessive under existing conditions. Whether this amount will eventually be considered sufficient, time alone will show. The allowance proposed is admittedly empirical, but it is founded on the East Indian Railway experience of 20 years, during which period three maximum floods have occurred in the Sone, attacking the line in a length of 26 miles. Whatever is done now on the Indus Valley Railway must to a certain extent be tentative. The total amount of waterway now provided between Kot Samaba and Sukkur is about 16,000 lineal feet, which was recommended by the Sukkur Conference to be increased to 17,700 lineal feet, supplemented by flood causeways between Kot Samaba and Khairpur.

Coming now to the question of the Kasimpur bund, I would certainly deprecate its extension to Pano Akil, unless there is any immediate fear of the Indus, as I see noted in one of the reports, deserting its course for the Narra. Taking into consideration the extra rise which may be expected in the floods, and the danger of permitting this rise to affect the river at Sukkur, it would be inexpedient to prolong the bund, and thus tend to aggravate, although, perhaps, only to a slight extent, the afflux already existing. The best method of meeting the difficulty would be, as already suggested, by opening out sufficiently large waterways higher up in the Railway, in order to pass off the extra spill that may be induced by the Kusmore bund, in addition to the extraordinary floods which now come down the river. If the floorings of the flood openings in the Railway are kept up to a proper level and efficiently protected, I see no reason to apprehend their being turned into ducts for a permanent change of the river. These openings will only come into play when the river rises to a certain height, and will cease to act when the flood falls below the river banks; and as long as the floorings and their protection exist, there can be no fear of the channel scouring back to the main stream, especially if the slope from the river to the level of the flooring is made less than that of the longitudinal flood surface down the river.

On the right bank of the Indus, the chief point of danger appears to be in the 10 miles of line, from mile 400 to mile 410 between Bhan and Sehwan, where the Kusmore and Begari spills, added to by the Jalli spill below Sukkur, unite with the Cutchee hill tract torrents, and after filling and overflowing the Manchur Lake burst across the Railway in enormous force. Outspills from the Kusmore and Begari floods, also combining with the Jalli spill, encroach on the Railway below Ruk.

The Kusmore bund will now keep out the two former floods, and an extension of the Jalli bund would apparently keep out the latter; but on this point I cannot venture to offer an opinion, as I did not have an opportunity of meeting the Superintending Engineer for Irrigation in Scinde, in whose charge are the embankments; and in the absence of local knowledge and information, it is impossible to say whether it would be advisable to extend the bund. If it was done, however, there would remain only the floods due to the hill streams and the overflow of the Manchur Lake to be provided for. Anyhow between Bhan and Sehwan it would be expedient to allow the full amount of waterway indicated as necessary by the flood of last year, and to raise the line at and below Ruk.

Official Inspection of the Indus Valley Railway, Upper and Lower Sections.

Note by Col. J. G. Medley R.E., *on the Inspection of the Indus Valley State Railway from Mooltan to Rohri.*

Dated Lahore, 12th April 1878.

I have just inspected the above line as directed by Government, and the following remarks refer *seriatim* to the headings indicated in Section I. of the Rules for the Inspection of Railways.

I. *Banks.*—The line is almost entirely in bank, varying up to 15 feet in height. The soil is throughout of a light sandy clay, occasionally of pure sand, and the banks are well consolidated, and not liable to slip. The width of formation surface is 19 feet; the side slopes* generally 2 to 1. At certain portions of the line the slope was certainly steeper, which the Engineer-in-Chief explained was owing to the bank not having settled down as much as had been expected.

Where the line passes through the heavily flooded country, the side slopes have been protected for some distance up by layers of brushwood pegged down. In other places, the tamarisk (farásh) bushes have grown

* Throughout the flooded tracts in the Ghotki and Reti Divisions the slopes are 3 to 1.

well. Where the *reh* soil predominates, as in many parts of the line, the slopes are bare. When the diversions lately made in the Shujabad Division are closed, the earth used to complete the main bank should be punned, if the line is to be immediately opened.

Cuttings.—There is a small amount of cutting through sand hills where the line passes through the desert (mile 150). Dead hedges have been made here along the crest to prevent the sand blowing down; possibly mud walling may be found useful here as in the desert road between Jhang and Dera Ismail Khan. There are also two rock cuttings close to Rohri, one of which, however, will be avoided by a new alignment now in progress. The other cutting stands nearly vertical, and is not likely to give any trouble.

II. *Curves.*—The only sharp curves on the line are those at the cuttings just mentioned, of which one, as already remarked, will shortly be dispensed with. The other (600 feet radius) is certainly sharper than is desirable, especially as it is on a gradient of 1 in 100. It was originally laid out for the metre gauge line, and will not be on the main line when the Indus bridge is built; but as that may not be for many years to come, I should recommend the improvement of this curve if possible. If not, the wheel base of all carriages travelling on it should be limited to 11 feet; my own carriage had 13 feet wheel base, and got round with difficulty. The type drawings of carriage stock for this line give a wheel base of 14 feet, which is certainly not safe on this curve; and there is another curve on the Sukkur river branch which has only a radius of 755 feet. The Engineer-in-Chief proposes, I believe, a special form of engine with bogies or sliding axles, to work this portion as a branch from the engine changing station where it diverges from the main line.

All the other curves on the line are good, the diversions having not less than 1,000 feet radius.

Gradients.—The only heavy gradients are the ones above-mentioned (on the river side branch) of 1 in 100, which are only objectionable as being on a curve, and will necessitate full break power being always available, and a limitation of rate of speed downwards to 10 miles per hour.

The other exceptional gradients are 1 in 200 on the approaches to the Sutlej bridge, which is, however, not yet completed, and a few short ones of similar grade on approaches to some of the arched bridges.

III. *Permanent way.*—The permanent way consists of a 60 lb. flat-bottomed iron rail secured by dog-spikes in the usual manner to transverse wooden sleepers, laid 3 feet apart (from centre to centre) except at the joints where they are 2 feet. The rails are fished at the joints in the ordinary manner, and the ends secured by either fang bolts or coach screws.

Rails.—The rails appear to me *generally* of good quality, but several instances were pointed out to me of rugged or broken edges; and the Engineer-in-Chief informs me he has made a special report on the inferiority of those supplied by the Birmingham Iron Works Company.

Sleepers.—The sleepers are partly of deodar and partly of English creosoted pine. The latter are 9′ × 9″ × 5″; the former are about 6 inches longer, and of the same section; of the deodar sleepers, the great majority appears sound, good timbers, but I also noticed a certain number which are decidedly inferior, full of knots and shakes. These, the Chief Engineer informs me, were chiefly cut from a quantity of timber which was taken over by order of Government from stocks in the hands of the Public Works Department at Naushahra and Mooltan.

The English creosoted sleepers looked to me sound and good; the only objections to them are, that they cost about 25 per cent. more than the deodar sleepers, and that unless covered, they are very apt to catch fire by any dropping ember from a train. I myself saw two or three instances of this.

Ballast.—The line is at present very imperfectly ballasted; on a short portion only is the ballast laid to the full standard section; on other portions it is partially or wholly absent. I do not myself see any objection to the sleepers being laid on the formation surface without any ballast, or at least on a layer of sand as a temporary arrangement in such a dry climate as this, provided that the surface ballasting be completed, but a thin layer on the surface, and for a width well clear of the ends of the sleepers, I look upon as indispensable, otherwise the rising dust will be an insufferable nuisance to passengers in the train, will damage the working parts of the engines, and may lead to accidents in a long train from the impossibility of the Driver and Guard seeing each other. I certainly look upon the completion of this surface ballasting as very necessary prior to the opening of the line, if not absolutely indispensable.

The ballast employed is almost entirely broken brick, partly from old mounds, but chiefly burnt on purpose, except at the lower end, where broken stone from Rohri is being laid.

IV. *Buildings.*—As to the "strength and quality of the structures above ground," all the packa masonry structures appeared excellent; I have indeed never seen better brickwork anywhere.

Kacha buildings.—There are, however, a considerable number of kacha buildings (chiefly stations) which have already cost a good deal in repairs, and are likely, I fear, to cost a good deal more. Owing to the prevalence of *reh* in the soil, it appears generally ill-adapted for kacha masonry, and in presence of any damp from rain or flood, the kacha plaster and exterior (at least) of the masonry rapidly disintegrate, and safety of the structures is endangered.* This absorption of moisture does not appear to extend above a certain height from the ground, and probably had the foundations and lower 4 feet of these kacha buildings been constructed in packa, they would have been all right; as it is, it has been found necessary to underpin several of them for a certain height above the floor, and I certainly do not recommend any more kacha structures on this line. The Chief Engineer informs me that none have been built within the last two years, except the temporary staff quarters at Rohri built on top of a hill.

The roofing employed is either the packa arched domes which have stood well so long as the substructure is sound, and (in later structures) a flat mud roof on a single layer of square tiles.

It is a great pity that these "Collett domes," as I believe they are called, were not erected on more substantial walling; for they certainly form a very picturesque feature in a very dreary country, and if the verandahs had only been wider, would, I think, have been exceedingly well adapted to this country and climate.

V. *Waterways.*—With regard to waterways on the line, there is this peculiarity that with the single exception of the Sutlej there is, properly speaking, no drainage channel larger than a small culvert on the whole length. The bridges required are either for the crossing of irrigation canals or (and chiefly) for the passage of an uncertain amount of spill water from the Indus (and in one case from certain canals). As a separate report will hereafter be submitted on the Sutlej bridge, I refrain

* The old Shujabad station, which was being temporarily repaired, I condemned as unsafe on this account, and work was stopped.

from further allusion to it here. As to these flood openings, it would seem impossible by any theoretical calculation to determine beforehand what is a safe and necessary amount. Repeated observations for several years, and in some cases failure, appear to have decided the provision now considered necessary, and in the bridges more recently built, a special design has been chosen, with a view of being able to add to the original structure without waste of money.

Arched bridges.—The older bridges or viaducts were brick arches of 10 or 20 feet spans, on brick piers and abutments founded on a bed of concrete 2 feet thick, with inverts between the piers, and apron walls front and rear 8 feet and 13 feet deep. The abutments were finished off with retaining walls in the usual manner.

The bridges of this class look so good and substantial, that it seems a pity they were not continued throughout the line.

Girder bridges.—The later bridges are 40 feet plate girders on brick piers founded on 2 wells sunk 40 feet below the bed, the abutments being built exactly like the piers, so that additional openings may be constructed when necessary. There is no flooring between the piers, but a mass of loose brick or stone refuse 10 feet wide and 10 feet deep has been added round each pier. In lieu of retaining walls, the embankment is supported by a mass of loose bricks built up in steps, which it is calculated will, in case of scour, fall down and check it. Should heavy rain occur, I fear this loose brickwork will give trouble, and in a heavy rush through the bridge I think the bricks would be carried away. I should myself have preferred a revetment of fascines which, in case of scour, would have fallen down and slipped forward *en masse* acting as a mattrass, and in which after a year or so grass or jungle shrubs would have grown, which they cannot do in the bricks.

The provision of a reserve of broken bricks at each bridge has, I understand, been recommended by the Chief Engineer, and should undoubtedly be allowed in time for next floods.

40 *feet girders.*—With regard to these girders, the great majority (nearly 200) are of 40 feet span, constructed by Westwood, Baillie and Co., or McLennan and Co. Some (60) are, however, 12 metre (= 39·38 feet) girders, which were originally made for the metre gauge line, but have since been strengthened by an additional plate on the top and bottom flange. They are also only 12 inches in *width* in lieu of 16 inches

as in the 40 feet. I carefully tested two spans of each class, the deflection and oscillation being noted in each case under the weight* of the heaviest class of engine on the line loaded up with fuel and water, the results being given below. The engine was driven over at speed as well as being allowed to stand for 10 minutes with the driving wheels over the centre of the span, in both cases the recovery being complete after the passage of the engine. The deflection of the 12 metre girders was not greater than that of the 40 feet ones, but the former are certainly not so stiff as the latter, doubtless owing to their smaller width of flange; and I have recommended the addition of extra diagonal bracing between the present bars.

I also examined and tested one of the four and six metre spans, and a trough girder of 25 feet, the results being given below. It did not appear to me necessary to examine and test other bridges, which were the exact counterpart of those already inspected.

Testing of bridge girders.—Results of girder testing, Indus Valley State Railway bridges—

Diagram of engine and tender is given herewith.

Sections of 40 feet and 12 metre girders will follow.

Twelve metre girder bridge, one mile from left bank of Sutlej—Top flange strengthened; bottom flange unstrengthened; all others have *both* flanges strengthened. Deflection $\frac{7}{16}''$; oscillation $\frac{2}{16}''$.

Twelve metre girder bridge over canal close to Khanpur—Top and bottom flanges both strengthened. Deflection $\frac{6}{16}''$; oscillation $\frac{2}{16}''$.

Trough girder bridge, 25 feet span, between Khanpur and Kot Samaba —Deflection very slight; oscillation imperceptible.

Four metre and six metre spans—Deflection very slight; oscillation imperceptible.

Mangsi bridge—Nine 40 feet girder spans.
Three 12 metre do.

No. 7 span, 40 feet, McLennan and Co.—Deflection $\frac{6}{16}''$; oscillation $\frac{1}{16}''$.

No. 9 span, 40 feet, Westwood, Baillie and Co.—Deflection $\frac{6}{16}''$; oscillation $\frac{1}{16}''$.

No. 10 span, 12 metre—Deflection $\frac{6}{16}''$; oscillation $\frac{2}{16}''$.

* For a span of 40 feet and under, this is the greatest weight that in practice can be put on the bridge. The bending moments were carefully worked out for two engines as well, in order to ascertain this.

Separate cards were affixed to the top and bottom flanges of both right and left girders, but the results were practically the same. Of the 40 feet girders, there are still 72 to be erected at the lower end of the line (between miles 224 and 330), of which about half are rivetted up, and only require lifting and placing. All are on the line, and will be finished within the next two months.

VI. and VII. *Bridge parapets.*—There are no parapets or hand rails to any bridges. On the long girder viaducts there is no room for a footwalk clear of the rails, but a man could easily jump down on to the flat heads of the piers to escape a train. On the long arched bridges there are refugees on the abutment piers only.

VIII. *Fixed structures.*—Platforms (where made) and water columns are of the standard dimensions; there are no over-bridges or tunnels on this section of the line.

IX. *Bridge platforms.*—There are no bridge platforms, except in the arched bridges, the intervals between the cross sleepers of the girder bridges being left open. Planking and ballast have been proposed by Chief Engineer, I understand, in lieu of the corrugated plates provided in the type drawings. The wooden bed plates of the girders are generally protected from fire by a layer of gravel, and the Chief Engineer has promised that *all* will be so.

X. *Fencing.*—The line may be said to be practically unfenced, though in certain miles a partially successful attempt has been made to grow a double kíkar hedge; it has, however, been greatly injured by the severe frosts of the past winter, though it is sprouting from below.

The line will, I presume, be properly fenced before long. I would not prohibit the opening without fencing, even for night running, provided all the engines are furnished with cow-catchers, but even with these accidents might happen; and as, when the floods are out, the railway embankment would become, if unfenced, a general place of refuge for animals to escape from the floods, it is certainly not desirable that this risk should be run. I think that a proper wire fence, either on wooden or iron standards, should be fixed on the slope above flood mark, though the Chief Engineer proposes, I believe, a mud wall as a temporary measure.

XI. *Level crossings.*—Level crossings have been fixed in communication with the Civil Authorities, and appear to be sufficient in number. The approaches to them are ready, and generaly posts and a chain have been provided, and the gate-keepers' huts built, but some huts are still wanting, and there are no gates at present erected, though some are made. Of course until the fencing is completed, the matter is not urgent.

XII. *Mile-posts and gradient boards.*—Mile-posts have been erected, and the miles are further numbered on all the telegraph standards.

The Chief Engineer proposes to limit the gradient boards to all gradients steeper than 1 in 500, which appears quite sufficient.

XIII. *Points and crossings.*—Points and crossings are according to the standard pattern. Sidings are 2,000 feet long between the takes-off; a few are still wanting in the Ghotki Division, as rails have not been available; they are now being laid in.

XIV. *Blind sidings.*—Blind sidings where made at stations are according to standard, with fall of 1 in 150 towards the dead end; these will be all completed by 15th June.

XV. *Signals.*—The usual Semaphore main and distant signals have been erected at all stations, except two or three at the lower end, where the work is still in progress. In all those lately erected, the distant signals are worked from the station platform close to the main signal, as they should be. In the older stations at the Mooltan end they are worked from the points. The only objection to the former arrangement is, that with such a length of wire (800 yards) it is apt to get slack, and the signal does not work properly. But with the arrangement now common by which the slack can be taken up, there seems no difficulty in the matter, and I personally ascertained that those lately erected worked very well, though in some cases a more powerful lever might be desirable. I think the rule should be enforced everywhere. Of course the signals remain at 'danger' if the wire breaks or will not work. A stouter section of wire than that now in use is also desirable.

XVI. *Station platforms.*—The older stations at the Mooltan end have raised *platforms* with a brick coping, are of full width, 600 feet long, and ramped at the ends. But they have not yet been metalled; this, I presume, will be done. Chief Engineer informs me they have recently been prohibited at all 3rd class stations unless changing stations.

XVII. *Stations.*—The present state of accommodation available at stations is as follows.

* * * * * * * *

Crossing the Indus.—Rohri River Side Station, 281 miles; has a platform, ticket office and waiting rooms building, and covered shed is in course of erection. The station is defended from the river by a dry stone wharf wall, which is now (26th March) some distance from the edge of the deep water channel, and it is proposed to obtain access to the steam ferry* (which will be used for transit until the bridge is built) by a pier partly on piles, defended from scour by stone, and partly floating, for which purpose four iron barges have been purchased from the Bahawalpur State.

Proposals have, I understand, been made for a large steam ferry capable of taking over the whole or part of a train of carriages to be worked between Suttian island and the opposite shore. To carry out this must necessarily take time,. and, considering the cost† of the arrangement, it may be considered better to face the construction of the bridge at once. In either case the pier arrangement will be required for at least two or three years, and will, I think, be all that is required for passengers and light goods. For heavy goods there will doubtless be some trouble, but I think satisfactory arrangements‡ will suggest themselves as experience is gained from the lighter traffic, and I should certainly deprecate any proposal to defer through-booking for any description of traffic as soon as the line is completed to Kotri, otherwise, I feel sure, the present boat traffic will compete successfully with the railway.

Future development of traffic.—On the Sukkur side there is no difficulty at present in regard to the deep water channel, which is said to be permanent at the site of the river side station. The buildings here are similar to those on the Rohri side, but it is certainly objectionable to have the public road along the strand running between the river bank and station. Both here, indeed, and at the Rohri side, there is a great want of "elbow room," and I do not think the Railway authorities sufficiently appreciate the absolute necessity which I feel there will be of large station yards. The bridge cannot be built for years, and by the time it is built, full use, I am sure, will be found for every foot of ground now taken up. The older railways have suffered so much from the cramped arrangements that were made owing to want of appreciation of future

* The small steamer now used is altogether too small, and is in a very bad condition. It will probably be best to hire one or two steamers from the Flotilla, and it would be as well to do this in time.

† Not only the first cost, but the amount of dead weight that will have to be taken across.

‡ I see no reason why the pier should not have rails laid on it with cranes at the pier head.

traffic development, that I feel I cannot too strongly insist on the absolute necessity of making timely provision for future requirements. Such, I am sure, should be made at most of the stations on this line, and everything planned with an eye to future extension, as may be found necessary.

The Sukkur river side station is connected with the main Sukkur station by a deep cutting and sharp curve (775 feet radius). Here the buildings and staff quarters are in progress, but I did not formally inspect them. I understand that there is a break of nearly 20 miles in the Larkana Division, which is only waiting for rails that are all on the line, and will be quickly laid. There is another break at the Laki Pass, where the slopes of the heavy cuttings are giving trouble, as I expected. It is a pity that this portion was not constructed in open tunnel at the first.

Choice of right bank.—The Government, no doubt, had good and sufficient reasons for carrying the line down the right instead of the left bank, otherwise it is obvious to remark that if a line is ever constructed from Hyderabad to Bombay, either the Indus must be bridged at Hyderabad, or another and a competing line must be laid up the left bank to Rohri. The possibility of a future extension from Sukkur to Shikarpore and through the Bolan Pass to Central Asia was doubtless one reason for preferring the right bank, and it cannot be doubted that whatever the engineering difficulties, this reason is a very strong one.

XVIII. *Rolling Stock.*—The following is a list of the rolling stock at present available on the line:—

Rolling Stock actually on Indus Valley State Railway between Mooltan and Rohri on 28th March 1878.

Tank Locomotives, ...	5
Tender „	18
Covered goods,..	50
„ „ for passengers, ...	44
„ „ temporary, low-sided, ...	34
„ „ „ platform, ...	66
Low-sided wagons, ...	140
Ballast „	48
Goods or ballast brake-vans, ...	3
First class carriages, ...	2
Inspection „	2

Rolling Stock that probably will be on line, Northern Section, in May 1878.

Tank Locomotives, ...	*5*	..	5
Tender „	*0*	..	18
„ „ from England, ..	*5*	..	14
First class carriages, ...	*4*	.. (*a*)	8
Second „ „	*0*	.. (*b*)	7
Third „ „	*0*	.. (*c*)	66
Covered goods, ...	*0*	..	150
Low-sided wagons, ...	*140*	..	140
Ballast „	*48*	..	48
Brake-vans, ...	*3*	.. (*d*)	9

Of these, of course, a certain number will be required for construction and maintenance, and will not be available for traffic; these are shown in italics.

XIX. *Cow-catchers.*—Most of the engines now on the line are provided with cow-catchers, and all will be so fitted. I consider them indispensable, at least for night running, on this line until it is properly fenced.

XX. *Space and ventilation of passenger vehicles.*—The "sufficiency of space and ventilation in the passenger carriages" is a most important point on this line, where the heat for six months in the year is so great that no European would willingly travel except at night. Pankhas and the best available cooling apparatus should be provided for all first class carriages, and all carriages should have the fullest allowable height and width, and be provided with double roofs and sun-shades. I regret to see that end doors and outside platforms have not been provided in the standard plans for first class carriages on this line, and I sincerely hope this will be altered in building them. The same accommodation can be given, and there can be no question, I think, of the superior comfort of the arrangement to the traveller who can stand or sit outside and get fresh air.

The same remark applies to the inspection carriages, the only one I saw being quite unfit for the purpose.

(*a*). 2 East Indian Railway; 2 Inspection; 2 Adamwahan Workshops; 2 Calcutta and South-Eastern.

(*b*). 4 Adamwahan Workshops; 3 Calcutta and South-Eastern.

(*c*). 44 Converted goods; 12 Adamwahan Workshops; 10 Calcutta and South-Eastern.

(*d*). 3 Old Great Southern of India Railway repaired; 6 part of 44 fitted with brakes.

Third class carriages.—Due arrangements should of course be made against overcrowding in the third class carriages, especially in the hot weather, when the number allowed in a carriage should be reduced from 50 to 40. I consider this should be a standing order of the Traffic Department. Water should of course be supplied at stations in the usual manner, and I recommend the practice of running with unlocked doors.* It is done on the Punjab Northern Railway, where it tends greatly to the comfort of the passengers, who can thus get out directly the train stops, instead of being delayed until the doors are unlocked one by one and the tickets examined. The platforms should all be railed in, and the tickets taken at the exit gate.

XXI. *Working of line.*—The line will be worked by the line clear system in the usual manner, so that two trains will never be on the space between two stations at once, except when following under caution line clear.

Name boards.—I have omitted to state that *name boards* are required at *all* the stations, which of course should be supplied.

Watering arrangements.—The *watering arrangements* at stations are complete, except at one or two places at the lower end, where they will shortly be so.

Water is 10 *to* 30 *feet below surface; average is* 18 *feet.* 20 *feet of water in all wells. Diameter of well* 8 *feet.*—The water is everywhere raised by the Persian wheel into iron tanks (one to four units), whence the engine takes it by the crane in the usual manner. The water is said to be generally of fair quality, but there are certain bad stations where engines will only water on emergency, notably Channigote.

Fuel.†—The *fuel* used is everywhere wood, chiefly tamarisk; doubtless when the line is open to Kotri, it will be found economical to use English coal up to a certain point varying with the prices of wood and coal and the rate of freight to Karrachi.

Sutlej bridge.—I may now Note the present state of affairs at the unfinished *Sutlej bridge*, which is as follows :—

Of the 16 spans, 8 are completed, 5 in hand, 3 not begun. Barring accidents, the bridge should be finished by 15th June.

* *i. e.*, on the platform side.

† Present price of fuel is Rs. 21 per 100 maunds between Mooltan and Reti; between Reti and Radhan Rs. 15 per 100; between Radhan and Kotri Rs. 22 per 100 (babúl).

The river at present runs favourably, the long protective spur on the left bank having apparently succeeded in arresting the tendency of the stream towards that side. This spur is protected on the river face by large quantities of brick cubes (one foot sides), which are made at about half the cost that stone can be brought down, but which are inferior from their lower specific gravity and tendency to break and be washed away in detail. I believe the one foot cubes at the Chenab have been found *two miles* below the bridge site, and it may be as well to note this danger.

Temporary bridge.—The temporary rail bank crosses the river a little above the bridge, the deep channel being passed by a pile bridge 700 feet long, which appears well and solidly built, and which is carefully watched. Mr. Bell hopes to maintain this until the opening of the bridge, but it is of course liable to interruption at any time.

Crossing the Sutlej.—The carriages are pushed across the temporary bridge by the engine from one side, and then pulled on by the engine on the other, where they are dragged up the diversion and backed on to the main line. All this, of course, causes a certain amount of delay; and considering the possibility of interruption to the temporary pile bridge, and the importance of the energies of the staff not being diverted in any way from the rapid completion of the main structure before the floods, I do not recommend this portion of the line being opened for traffic until the bridge is finished.

I shall of course comment further on the bridge itself when I inspect it after completion.

Concluding remarks and recommendations.—Having now, I think, gone through all the points noted by Government as specially requiring consideration, and added such other notes as have occurred to me, I may sum up by remarking—

1st.—That the section from Mooltan to Adamwahan is now ready for traffic as far as the way and works are concerned, and there is sufficient rolling stock for passenger traffic. This then might be opened at once, with the proviso that as the line is unfenced, all engines must be provided with cow-catchers.

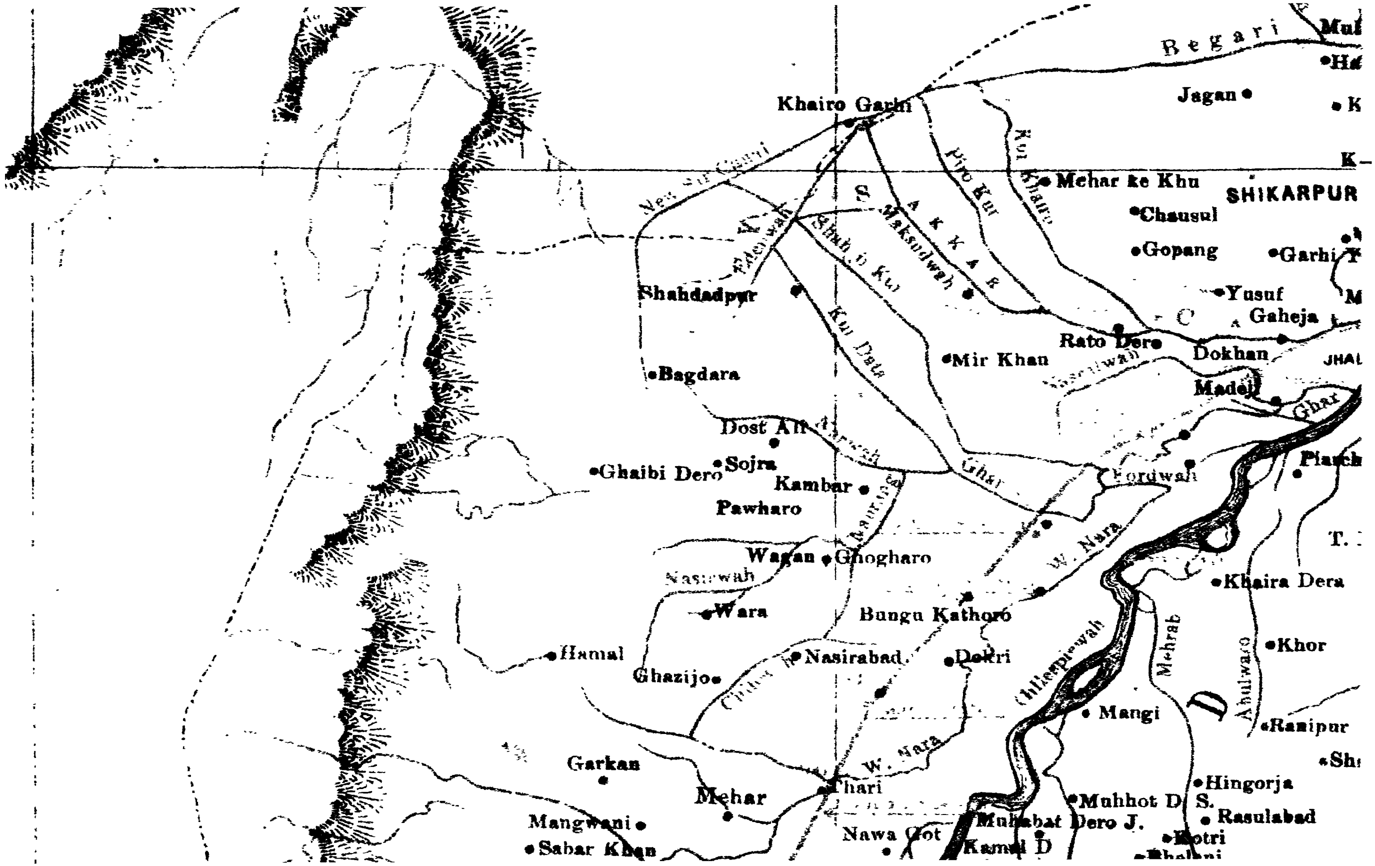
2nd.—The Sutlej bridge will probably be ready by 15th June, by which time it is expected that the remainder of the 40 feet girder bridges will also be finished; the signals ready at all stations, and additional rolling stock provided, sufficient for a moderate passenger and goods traffic down to Rohri, but 70 miles of the line will still be quite unballasted even on the surface. This cannot be ready in time, as it is necessary first to complete the protective work round the piers.

This need not, however, prohibit the opening of the line, but every exertion should be used to complete this surface ballasting as fast as possible.

3rd.—Beyond Rohri there is reasonable hope of the line being ready for running down to Kotri by 15th June, but I have not inspected that portion.

4th.—Through booking beyond Rohri cannot take place until the piers and ferry arrangements are complete, and these should be pushed on so as to be ready by the time the line is opened to Kotri.

5th.—The advantage of opening by sections so as to train the Traffic staff it is needless to comment upon.


Regari
Jagan
Khairo Garhi
Mehar ke Khu
SHIKARPUR
Chausul
Gopang
Garhi
Yusuf
Gaheja
Piro Kur
Kur Khairo
Maksudwah
Shah ji Kur
Shahdadpur
Rato Dero
Dokhan
Mir Khan
Kur Data
Bagdara
Madeji
Ghar
Dost Ali
Sojra
Ghaibi Dero
Kambar
Pawharo
Fordwah
W. Nara
Wagan
Ghogharo
Khaira Dera
Nasirwah
Wara
Bungu Kathoro
Hamal
Ghazijo
Nasirabad
Dokri
Mehrab
Khor
Mangi
Ranipur
Garkan
Mehar
Thari
Hingorja
Muhhot D.
Rasulabad
Mangwani
Sabar Khan
Nawa Kot
Kamal D
Kotri

No. CCCXVII.

TRIAL OF FOURACRES' PATENT AUTOMATIC DREDGER.

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

BY R. B. BUCKLEY, ESQ., *Exec. Engineer, Eastern Sone Division.*

THIS dredger has now been subject to a carefully conducted trial for ten weeks in the Eastern Main Canal for the purpose of practically testing its powers, both as regards the quantity of work it can perform, and the cost at which it can do it. A Sub-Overseer was especially deputed to work the dredger, and to record all the facts necessary to lead to a correct judgment on the value of the invention.

The particular dredger used was one principally composed of such machinery as was available in the Dehree workshop: the actual excavating bucket itself, and its immediate fittings, in which the essence of the invention lies, being, of course, quite new. The dredger was worked by a 6 horse-power portable engine, which drove a 1½ ton crab winch, the excavating bucket being swung to a portion of an old travelling crane. The accompanying drawings show the general arrangement of the dredger itself, and the details of the excavating bucket, which had a capacity of 16 cubic feet. The dredger was accompanied by six mud punts, which were fitted with removal sides, so that the silt could be easily scraped off from the decks. It was found during the trial that this number was just sufficient to keep the dredger in full work when the lead, from the dredger to the spot where the silt was thrown into the river, did not exceed about half a mile. The silt in each punt was levelled off and measured before it was discharged into the river.

The actual cost of the dredger (some allowance being made for the fact that the engine and winch were not new) is given by Mr. Fouracres at Rs. 6,111, but it is estimated that a dredger specially, and of course better, constructed, of machinery intended for the purpose, and not merely adapted, as in this case, would cost almost Rs. 8,000. Each mud punt cost Rs. 4,000. The value then of one of Fouracres' Patent Dredgers, with the necessary number (six) of mud punts, is about Rs. 32,000.

Mr. Fouracres' specification describes the action of the Dredger as follows:—*See Figs.* 2, 3 and 4.

"The main lifting chain, B, is attached to an engine or crab winch with suitable crossed and direct straps and loose pulleys, &c., or any suitable arrangement such that the man, who regulates the machinery, can wind up or unwinch the chain, or hold it stationary at any moment he pleases. The dredger is first lowered into the water, in the position shown in *Figs.* 2 and 3, by unwinding the main lifting chain, B, from the engine while it is being lowered. This chain is, of course, tight, as it bears the whole weight of the bucket, the long wooden spear, and of the whole movable part of the machine. The strain on the main lifting chain tends, of course, to draw the travelling collar, W, upwards on spear L. This tightens the closing chains, P, the strain on which, acting on the semi-circular angle irons, O at R, tends to close the scoops of the bucket. These scoops are only prevented from closing by the catch T, which holds the two scoops together at the top and prevents their closing. In this manner the bucket descends, the wooden spear C sliding freely down in its guides, D and E.

"When the bucket reaches the bottom, which it generally does with somewhat of a blow if the engine be run quickly, the two scoops M are pressed upwards as it were. As the strain is thus taken off the catch T, it rises by means of the flotation of the ball attached to it, and thus the scoops are released and free to close. At this period the stops S come into action; they prevent the scoops from opening more than is just sufficient to release the catch T. Immediately the catch T is open, the engineman (or the man who is working the winch) reverses the winch and the main lifting chain begins to ascend. At this moment, also, the lever G is pulled over by the rope attached to it; this jams the spear C tightly in the guide E by means of the cam F. The main lifting chain, as it ascends, draws the travelling collar W up the spear L. As this collar W ascends, it draws up the closing chains P; these draw the semi-circular angle irons O towards the sheaves Q, which are fixed on the spear L, and the scoops of the bucket are gradually closed upon the silt or mud; the spear all this time being held fast in the jib head by the cam, and the jib being fixed so that it cannot rise, the bucket is compelled to bite into the soil, *Fig.* 4. As soon as the bucket is closed (and this can be told easily by a mark on the spear to which the collar X will descend) the lever G is released, and the whole apparatus rises to the surface. As the bucket rises above the water, the crane A is revolved until the bucket hangs over the mud punt, which is moored alongside the dredger. When the clutch collar X rises up to the hooks H, the projecting arms push back the hooks H, which immediately afterwards, by the action of the counterbalance weight K, fall back into their old position. As soon as the winchman sees that the hooks H have caught the arms of the clutch, collar X, he immediately reverses the winding of the main lifting chain. The apparatus then descends; but as the clutch collar X is caught by the hooks H, the rods Y are placed in tension, the spear and the heavier portion of the dredger continue to descend, the scoops M are pulled open partly by the weight of the material they themselves contain, partly by the weight of the descending parts which press with all their weight upon the cross-head of the spear L, and thus tend to press open the bucket. When the scoops are widely open, the stops S bear on the spear L, and the catch T falls of its own account into position, catching the other scoop.

"The dredger is now ready for another lift; the slack of the main lifting chain is taken up by the engine, and the weight of the apparatus is lifted sufficiently to allow the hooks H to be drawn back by the rope which is attached to them. The winch or engine is then reversed and the bucket descends again as before.

"The engine (or winch worked up by the engine) has to be reversed three times during each lift. *First*, after lifting the apparatus from the hooks H, it has to be reversed to lower the bucket; *secondly*, when the bucket reaches the bottom, it has to be reversed to lift it; and *thirdly*, when the bucket is over the mud punt, it has to be reversed to empty the bucket."

The place selected for the trial of the dredger was the head of the Eastern Main Canal at Baroon; for this length the channel has a base of 180 feet narrowed suddenly at the 26th chain to 80 feet. This portion had silted up to an average depth of 2½ feet, there being 1,00,000 cubic feet in the first 26 chains. In some places there was as much as four feet of silt, the water being so shallow that the float of the bucket was occasionally not sufficiently immersed to act; this, and the fact that the mud punts often went aground while they were being loaded, caused occasional delay, but the difficulty was eventually overcome by closing the head sluices entirely during the night, so that, without increasing the total discharge of the canal, it was possible to raise the level of the water at the head during the day. During the first few days the dredger was employed on clearing out the lock channel, which was but slightly silted up, and then the dredger was put steadily to work to clear out a channel, about 50 feet broad, as shown by the dotted lines. The silt excavated was discharged into the river near the island, in such a position that it would be all cleared away through the under-sluices of the weir in the next flood.

The dredger was first started (in the narrow lock channel) with the regulating apparatus designed by Mr. Fouracres, who describes it as follows:—"The dredger boat is secured in position as shown in the plan, *Fig.* 5, by a T strut, the base of which rests on the bank, has two loops fixed on it through which iron pins are driven into the bank; the other end of the strut has an eye attached to it which works on a pivot fixed to the stern of the boat, and thereby enables the boat to move in an arc, of which the pivot is the centre. To the bow of the boat (the end where the excavator works) is attached a piece of quartering, working similarly to the strut, *viz.*, on a pivot, and of a length sufficient to enable the bow of the boat to be moved to a few feet beyond the half width of the canal. This piece of quartering is, for convenience sake, marked into divisions (four feet in the present case) equal to the size of the excavator when fully opened. After the excavator has taken its first bite the boat is shoved off the distance of one of these divisions, and ready for the excavator to descend and take its second bite, and so on until the canal is cleared to its half width; if in passing over the first time the dredger does not excavate the full depth required, it can be worked in a similar manner back again; but if the desired depth is obtained after the first arc is travelled over, the T strut and quartering pieces are moved either up or down stream, as may be desired, a distance equal to the breadth of the excavator (2 feet 6 inches in this case), and the dredger travels over an arc parallel to, and at a distance from, the former equal to the breadth of the excavator. The moving of the dredger, as above described, is effected by men placed on the bank with a light two-fold block and a 2-inch rope attached to it, one end to a leg on the bank, and the other to the quartering or pole. This system entirely dispenses with chains or anchors, and has found to answer the purpose admirably. The successful and economical working of the dredger greatly depends on having good, sharp men to move the dredger backwards and forwards."

This arrangement, though perhaps suitable in some places, as for instance if it were required to clear out a channel 40 or 50 feet wide near the edge of a wide channel where the T strut could be conveniently attached to the bank, is not good for a wide canal, like the Eastern Main Canal of 180 feet base, nor is it even applicable for clearing out a channel as was done at the trial. Indeed, it appears doubtful whether a well-arranged system of anchors is not in all cases preferable, except perhaps where there is very heavy traffic, for this system has the advantage of leaving one side of the canal entirely open for boats. The T strut is cumbersome, and three or four men are required to push in and out of the regulating bar. This plan of regulating the dredger was then abandoned, as soon as the excavation of the 50-feet channel was commenced and the following arrangement was adopted:—A small gipsy winch (A in *Fig.* 6) was fitted on two uprights to the edge of the dredger; a small capstan would have been more suitable, as the regulating chain B would not have jammed on a capstan in the same way as it did on the winch. A man stationed at this winch A was able easily to regulate the movements of the dredger, causing it to oscillate in the arc C, D. The two anchors attached by ½-inch chains to a bollard on the stern of the dredger kept the point E very nearly stationary; the action of the current tended, of course, to keep the anchor chains tight. Occasionally, as the stream varied, the dredger would perhaps float slightly out of its proper course, in which case the bucket would come up very nearly empty; but this did not occur very frequently. When the dredger had worked up to the point C, the anchor chains were slackened by about 2 feet 6 inches (the width of the bucket); the winchman then reversed his winch, and gradually brought the dredger back to the point D; some care is necessary in thus regulating the dredger; when it is found that the bucket comes up with the silt piled up above the top of the bucket, the winchman should allow the bucket to take another bite at the same spot, or the channel will not be entirely cleaned out. When the dredger had worked up to the point D, the anchor chains were again slackened by $2\frac{1}{2}$ feet, the gipsy winch was reversed, and the dredger ate her way back again to the point C, and so on continually. Occasionally, when the anchor chains became long, and the dredger was perhaps somewhat swept off her course by the action of the current, or when the anchor chains had been slackened by more than the width of the bucket, a ridge of silt would be left; but, as a general rule, the channel was very fairly cleaned.

Some difficulty was at first found in managing the mud punt in the stream; the silt came up generally so dry and hard that it was necessary to move the punt frequently, so that the silt might be deposited all over the punt; in order to regulate the movements of the punts, iron hooks were fastened about 6 or 8 feet apart all along the side of the punt, and small wooden stanchions were fixed at about corresponding intervals on the side of the dredger; two ropes were hooked on to the mud punt, as occasion might require, and the coolies, by loosening or hawling on these, were easily able to regulate the position of the punt. Another rope stretched right across the stream was used, both to keep the stern of the mud punt in any required position, when she protruded a long way beyond the nose of the dredger, and thus was not fully under the command of the coolies on the dredger, and it was also used as a means by which the empty punt was hauled across the stream to the dredger, as soon as the former one was full. Two pair of bullocks towed the full punts up to the lock and brought back the empty one.

The silt excavated varied from pure sand to soft black mud; the heavier particles, *i. e.*, the sand, were of course deposited near the head sluice; the silt gradually became less and less sandy and more and more muddy the further the dredger worked from the sluices. One of the greatest advantages of this dredger is that it brings up the silt quite dry and hard; the greater portion of the silt which has been excavated during the present trial could have been at once carried away on coolies' heads in baskets if necessary. It is also remarkable how little the dredger stirs up the mud in the canal; it works most cleanly, taking its bite without disturbing the silt near it; in this respect it is much superior to other dredgers. The leather valve in the bucket acted capitally; whenever the bucket came up at all empty most of the surplus water fell out into the canal before the crane had revolved over the mud punt. It was noticed that in the pure sand the bucket frequently came up only half full, but that in the mud it frequently brought up as much as 20 cubic feet; the bucket will not bite fully into hard sand, as at present constructed, for the spear rises even though the lever be most tightly pressed against it. Mr. Fouracres proposes to attach a rack to the spear, so that it will be impossible for it to slide in the jib-head. The full capacity of the bucket is 16 cubic feet; but on the average it only brings up 12 cubic feet each lift; this is due partly to bad regulation of the dredger, partly to sand being hard to cut, and partly to the fact that if the bed is thoroughly cleaned out it is not always possible to give the bucket a full bite. An average of 45½ buckets can be lifted per hour, and the average quantity excavated per working day has been 3,691 cubic feet. The greatest quantity ever done in one working day of 9½ hours was 4,647 cubic feet. In ten weeks 210,132 cubic feet have been excavated.

The following establishment was employed in working the dredger and regulating the mud punt:—

Labour.

No.	Description.	Rate.	Amount.	
		RS. A.	RS. A. P.	
1	Driver, ...	4 0	0 4 0	Driving the engine.
1	Winchman,.. ..	4 0	0 4 0	Ditto winch.
1	Fireman, ...	3 0	0 3 0	Firing the engine.
1	Jibman, ...	3 0	0 3 0	Working the hook and lever of the crane.
1	Gipsy winchman, ..	2 6	0 2 6	Regulating the dredger.
6	Coolies, ...	2 6	0 15 0	Moving mud punt.
2	Wood-cutters, ..	2 6	0 5 0	Cutting wood.
1	Boat, with manjee,	5 0	0 5 0	Taking off men and firewood to the dredger, and carrying tow rope to mud punt.
	Extra allowance, ..	..	0 6 0	Allowance of 1½ annas per 1,000 feet made to men for each 1,000 cubic feet in excess of first 2,000 feet.
		..	2 15 6	

The following were the principal materials consumed each day:

Materials.

Kind.	Weight.	Rate.	Amount.
		RS. A. P.	RS. A. P.
Fire-wood, ... mds,	11	0 2 0	1 6 0
Castor-oil, ... lbs.	2	0 3 2	0 6 4
Grease,.. .. .. ,,	1	0 3 4	0 3 4
Jute, ... ,,	1	1 6 0	0 1 6
Total Materials, ..	..	..	2 1 2

The following establishment was kept up for hauling the mud into the river:—

No.	Labour.	Rate.	Amount.
		RS. A. P.	RS. A. P.
2	Bullocks,..	5 0 0	0 10 0
2	Mullahs,..	2 6 0	0 5 0
10	Coolies, ...	2 0 0	1 4 0
8	Ditto, ...	1 6 0	0 12 0
	Total Rs., ..	..	2 15 0

An accurate daily account was kept of all expenditure, all materials used were carefully weighed, the time taken in loading each barge was taken by the Sub-Overseer, one of the lascars was appointed to count the number of buckets lifted. The accompanying Tabulated Statement shows the results of the ten weeks' trial. A total quantity of 210,132 cubic feet have been excavated and discharged into the river, with an average lead of about 1,800 feet, at a cost of Rs. 2-4-3 per 1,000 cubic feet. The average cost per 1,000 cubic feet of the silt delivered into the punt has been Rs. 1-6-8, and the average cost per 1,000 cubic feet of hauling the punts to the river and discharging them has been Re. 0-13-7. The cost here given is of course only the actual working charges, independent of repairs and interest of the original cost of machinery.

The original cost of one of Fouracres' Patent Dredgers of six horse-power, together with six mud punts, is about Rs. 32,000, allowing 15 per cent. for interest and depreciation, and 5 per cent. for repairs.

The yearly charge for these items amounts to Rs. 6,400, or say Rs. 22 per working day, or about Rs. 6 per 1,000 cubic feet. The full cost then of dredging by this dredger is per 1,000 cubic feet—

	RS.	A.	P.
Repairs, interest and depreciation, ...	6	0	0
Working charges, ...	2	4	0
Total Rs., ...	8	4	0

The cost of excavating silt from this same canal by hand labour, after the canal was run dry, was in 1877 Rs. 5-8-0 per 1,000, and in 1878 Rs. 6-4-0 per 1,000. The silt was all carried to the top of the large spoil banks. The cost of clearing the canal in this way must, of course, yearly increase, as the spoil banks become larger and larger.

The actual cost of one of an ordinary ladder and bucket dredger of 15 horse-power is about Rs. 53,600; these dredgers are supposed to excavate 4,000 cubic feet of silt per hour; but it has been found by the Executive Engineer of the Midnapore Canal that, under the most favourable circumstances, the actual performance does not exceed 2,000 cubic feet per hour. The working expenses of these dredgers in the Midnapore Canal amounted, in 1875-76, to Rs. 10-12-0 per 1,000 cubic feet, the lead was longer by about one-fourth mile than was the case at the trial of Fouracres' Patent Dredger. If one of these dredgers worked under the most favourable circumstances, she could excavate about 12,000 cubic feet per day, and would require from 20 to 24 mud punts, costing about Rs. 80,000 to keep her in full work, making the full cost of dredger and punts Rs. 1,34,000. Taking 15 per cent. for interest and depreciation, and 5 per cent. for repairs, the yearly charge of these items amounts to Rs. 26,800, or say Rs. 90 per working day, or Rs. 7-8-0 per 1,000 cubic feet. The cost of dredging by the ordinary ladder and bucket dredger per 1,000 cubic feet is—

	RS.	A.	P.
Repairs, depreciation and interest, ...	7	8	0
Working expenses, ...	10	12	0
Total Rs., ...	18	4	0

It is more than probable that the working expenses of these dredgers might be reduced below Rs. 10-12-0 per 1,000 under favourable circumstances; but the dredgers, working in the Midnapore Canal, have never worked for less than that, and latterly have cost Rs. 13-11-0 per 1,000 cubic feet. The great wear upon the links and pins of the ladder and bucket dredger soon causes the chain of buckets to sag down, the buckets then foul the edge of the well unless the beam is raised, which, of course, reduces the depth to which the dredger can cut; there is often difficulty also in getting the buckets of the ladder dredger to empty themselves if the silt is at all stiff. Concerning this difficulty, the Executive Engineer of Midnapore Canal (Mr. Apjohn) writes: "The sandy silt could not be made to come out of her buckets until they had so far passed the vertical that it would not fall into the shoot, consequently we had to allow it to fall on the deck, and shoved it into the mud barge alongside. Of course, this reduced the dredging power to a minimum, and I think that 3,000 cubic feet per day, the best that was ever yet got out of her, also the resistance of the hard silt, was so great that her level gearing was always breaking its teeth in the effects to force the buckets through. Altogether, for canal work, I condemn the bucket dredger."

Fouracres' Patent Dredger appears admirably adapted to excavate silt from canals. One of its greatest advantages for India is that it can be readily constructed from machines—a portable engine, a crab winch, and a crane of any kind—that are generally available on any large works in this country. It is very simple, easily managed by natives, and the working parts are so simple and light, that they can easily be repaired by any intelligent fitter. The cost of working is much less than that of other dredgers, and even including the charges for depreciation, interest and repairs, the cost of the work done does not largely exceed that of hand labour when the canal is dry. Three of these dredgers in the Patna Canal (83¼ miles in length) would probably, if kept constantly at work, keep the canal clear of silt, and obviate the necessity of closing the canal yearly for the purpose of clearing it out. It is difficult to exaggerate the immense advantage this would be.

6th February, 1879.

Abstract showing the weekly cost of working Fouracres' Patent Dredger.

Week ending.	Time taken in filling mud punt.	Number of buckets put in punt.	Cubic feet in punt when loaded.	Cubic feet lifted by bucket.	Number of buckets per hour.	Time dredger was actually working.	Time men were employed.	Quantity excavated.	Cost of delivery into mud punt per 1,000 cubic feet.	Lead of punts.	Cost of discharge into river per 1,000 cubic feet.	Cost per 1,000 discharged into river.	Quantity excavated, cubic feet.	Amount expended in delivery into mud punt.	Amount expended in haulage to river and discharge.	Total expenditure.
	AVERAGE OF EACH WEEK.												TOTAL OF EACH WEEK.			
						Each day h. m.	Each day h. m	Each day.	RS. A. P.		RS. A. P.	RS A. P.		RS. A. P.	RS A. P.	RS. A. P.
Saturday, Nov. 2nd	0-51	39·3	467	12-0	42·5	5 31	...	3,210	1 4 6	1,200	1 0 2	2 4 8	22,474	28 12 1	22 11 0	51 7 1
9th	0-53	36·1	426	12·4	40·1	6 36	9 17	3,135	1 9 3	1,300	1 2 0	2 11 3	15,677	24 11 9	17 10 0	42 5 9
16th	0-53	37·1	454	12-2	42·1	6 27	8 32	3,604	1 10 1	1,400	0 13 11	2 8 0	18,022	29 7 9	15 8 6	45 0 3
23rd	0-49½	39·4	465	12-0	47·6	6 39	7 58	3,762	1 8 5	1,500	0 13 9	2 6 2	22,572	34 10 3	19 3 3	53 13 6
30th	0-50	39·6	468	11-8	47·7	6 20	8 33	3,625	1 6 2	1,600	0 14 10	2 5 0	21,752	30 6 6	19 14 0	50 4 6
Saturday, Dec. 7th	0-50	41·3	466	11-2	49 0	7 27	9 6	4,172	1 3 8	1,800	0 12 0	1 15 8	25,033	30 10 11	18 11 6	49 6 5
14th	..	39·6	475	11-6	...	...	...	3,839	1 7 6	1,900	0 14 1	2 5 7	19,194	28 3 0	16 14 6	45 1 6
21st	0-53	40·5	483	11-9	44·4	6 41	8 54	3,622	1 7 0	2,000	0 12 1	2 3 1	21,732	31 2 0	16 6 0	47 8 0
28th	0-49	41·1	486	11-8	50·5	6 53	8 25	3,991	1 6 7	2,100	0 12 2	2 2 10	19,956	28 8 0	15 3 6	43 6 6
Jany. 4th	...	40·6	483	11-4	...	...	...	3,953	1 5 0	2,200	0 11 3	2 0 3	23,720	31 1 5	16 12 0	47 13 5
Total,...	6-48	394·6	4,673	118-3	363 9	52 34	60 45	36,913	14 4 2	...	8 10 3	22 14 6	2,10,132	297 4 3	178 14 3	478 2 11
Average,...	0-51	39·4	467	11-8	45·5	6 34	8 40	3,691	1 6 8	...	0 13 7	2 4 3	...	...	...	...

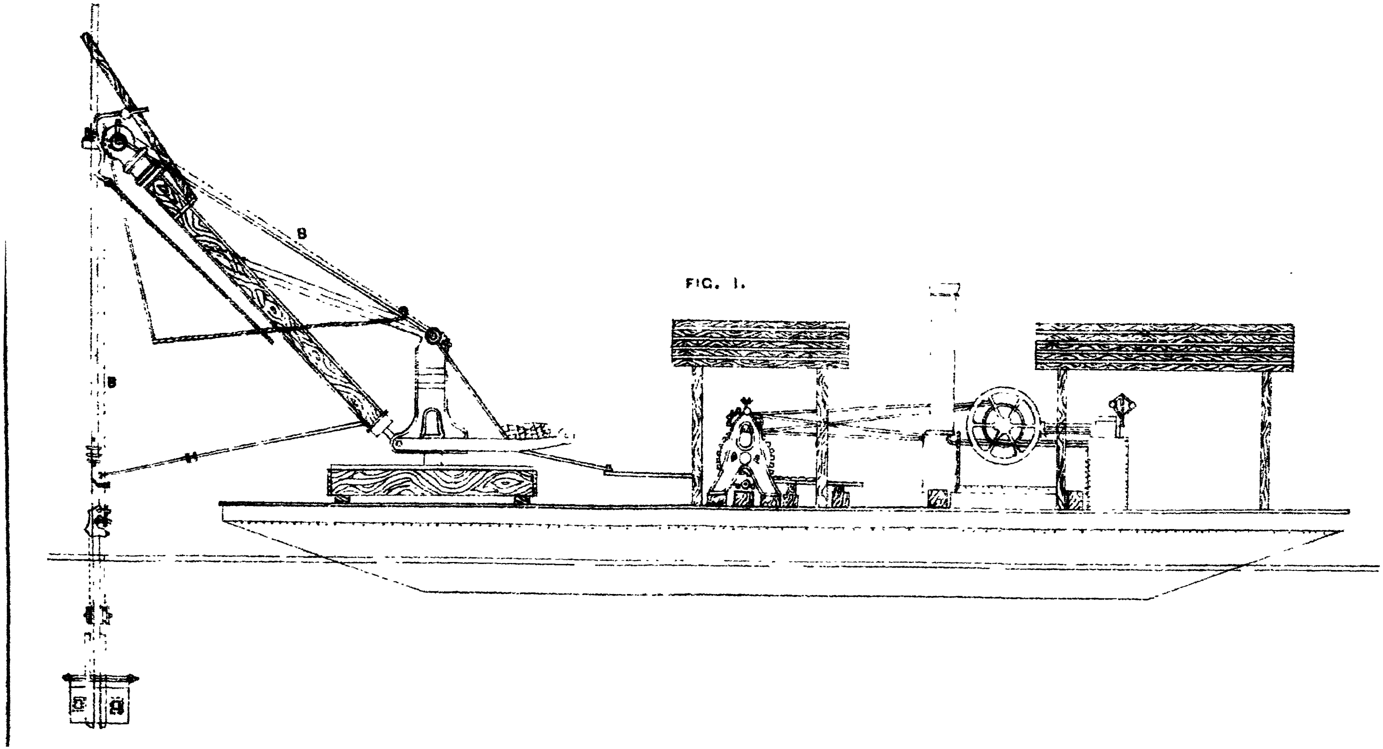
P.S.—Since the above was written Mr. Fouracres has attached to one of his dredgers the rack referred to in page 421 of the report. The rack is attached to the spear of the dredger, and is so constructed that the cam of the lever retains the spear fixed in the jib-head while the scoops are cutting; the spear therefore cannot rise, and the scoops are compelled to take their full bite. This arrangement acts well. It has been working this morning in pure sand. The bucket came up nearly full each time, whereas without the rack only about half a bucketful was raised. The dredger now acts capitally in pure sand. The rack is so arranged that if any very great resistance, such as a large stone or log of timber, be met with, the cam jumps out of the rack without damage being done to any of the working parts.

DEHREE :
27th February, 1879. R. B. B.

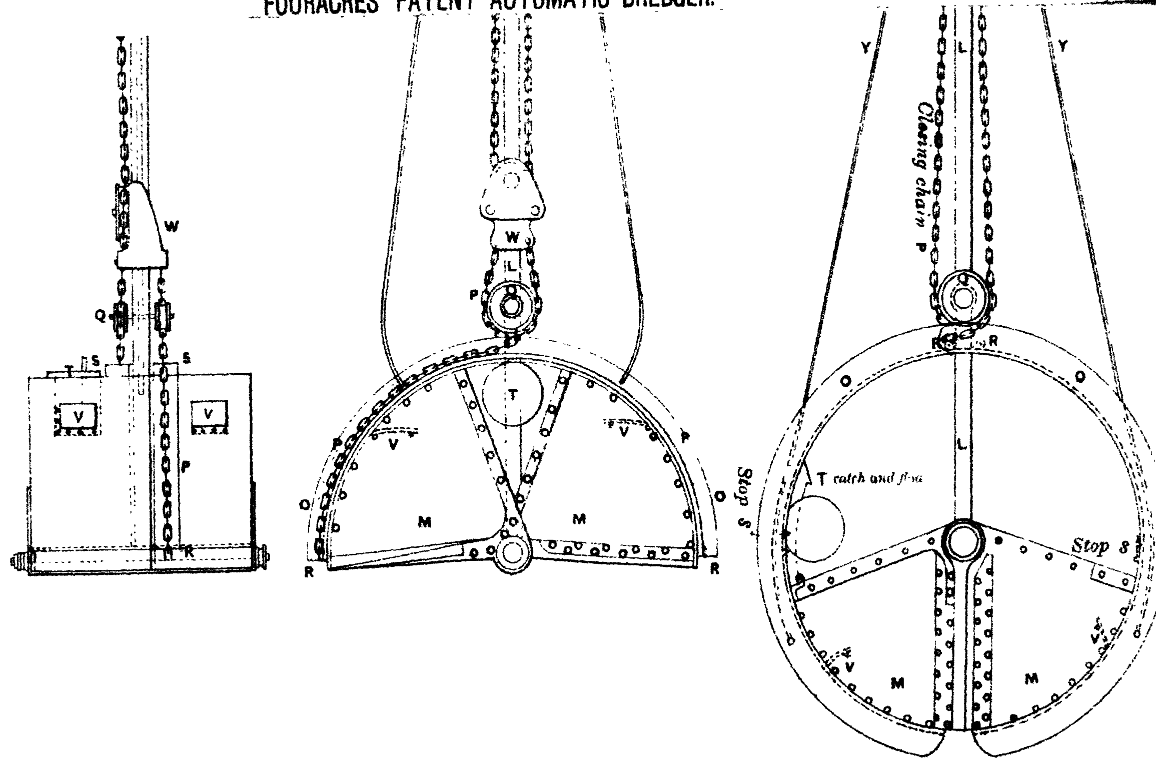
FOURACRES' PATENT AUTOMATIC DREDGER.

Scale. ¼ inch = 1 foot.

FIG. 1.



FOURACRES' PATENT AUTOMATIC DREDGER.



FOURACRES' PATENT AUTOMATIC DREDGER.

Scale. ⅛ *inch* = 1 *foot.*

Fig. 5.

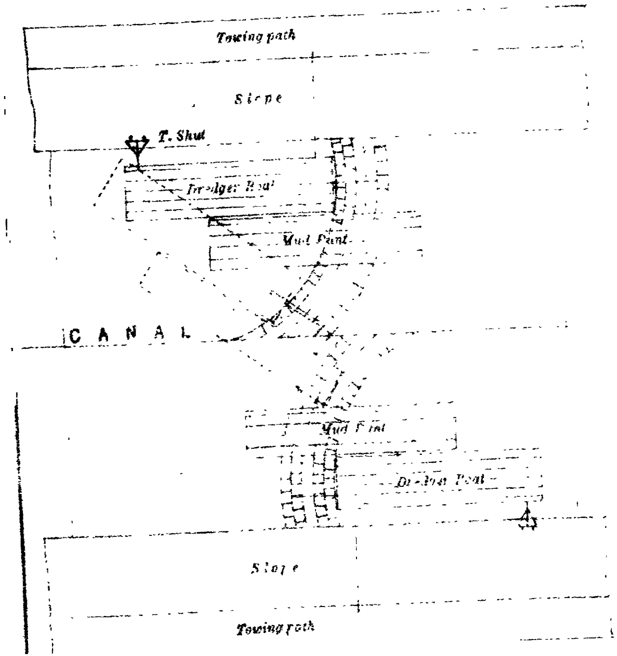
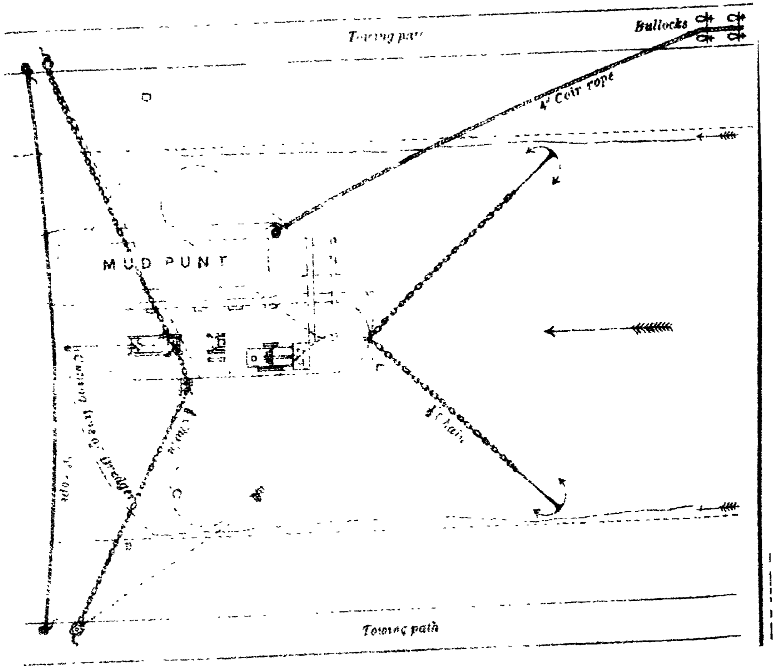


Fig. 6.



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INDEX TO VOL. VIII.

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LIST OF PLATES.

LITHOGRAPHS. PAGE.

ALPHABETICAL INDEX.

E.

F.

G.

H.

I.

R.

S.

T.

LIST OF AUTHORS.