

PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING.

[SECOND SERIES.]

EDITED BY
MAJOR A. M. BRANDRETH, R.E.,
PRINCIPAL, THOMASON C. E. COLLEGE, ROORKEE.

VOL. IX.



ROORKEE:
PRINTED AND PUBLISHED AT THE THOMASON COLLEGE PRESS.

1880.

[*All rights reserved by the Secretary of State for India in Council.*]

BOORKEE :
THOS. D. BONA, SUPERINTENDENT,
THOMASON COLLEGE PRESS.

INDEX to VOL. IX.

(SECOND SERIES).

	PAGE.
Action of Falling Water, On the. By J. S. Beresford, Esq., Exec. Engineer,	63
Centre of Gravity of a Polygon graphically, To find the. By the Editor,	13
Clip Calliper for lifting Waste Weir Planking. By A. Hayes, Esq., Assistant Engineer, Cossye Division,	263
Comparative Working Expenses of Broad and Narrow Gauge Railways, Papers on the. By Mr. E. B. Carroll, M. Inst. C.E., Locomotive and Carriage Supdt., Bombay, Baroda and Central India Railway—Lieut. H. Pilkington, R.E., Acting Depy. Con- sulting Engineer for Railways—Mr. J. O'Connell, Chief Auditor and Accountant, Bombay, Baroda and Central India Railway Company, and Mr. A. M. Rendel, Consulting Engineer for State Railways to the Secy. of State for India,	141
Dynamite, Alfred Nobel's. By Major J. L. L. Morant, R.E., Exec. Engineer,	275
Electrical Inter-Communication in Trains. By G. K. Winter, Esq., F.R.A.S., M.S.T.E., Telegraph Engineer, Madras Railway,	267
Experiments made to determine the true Co-efficient of the Dis- charge of the Head Sluice of the Midnapore Canal, Note on. By J. W. Apjohn, Esq., Exec. Engineer, Cossye Division, ...	49
"Flexible Wheel-base" or Radiating Axles, James Cleminson's,	259
Iron Ore and Coal from the Chánda District of the Central Pro- vinces of India, Report on the. By Mr. W. Hackney, ...	185
Inspection Notes—Panjab Railways. By Col. J. G. Medley, R.E., Consulting Engineer for Guaranteed Railways,	15
Inter-Oceanic Canal Projects. By A. G. Menocal, Esq., C.E., Member of the American Society of Civil Engineers, ...	103

Inter-Oceanic Canal Projects,	223
Moveable Dams. By R. Burton Buckley, Esq., Exec. Engineer, Bengal,	125
Sleepers for India, Enquiry into supply of,	95
South Pass Jetties of the Mississippi, The. By the Editor, ...	1
Water Supply, Almora. By T. W. Ashhurst, Esq., Exec. Engi- neer, Kumaon Division,	351
Water Supply, Ahmedabad. By Lieut. J. Neville, R.E., Exec. Engineer,	353
Water Supply, Aden. By Lieut. H. Clarke, R.E., Exec. Engineer,	359
Water Supply by means of steam pumping for the European Troops of the Hyderabad Subsidiary Force at Secunderabad, Descriptive account of the system of. By Capt. H. C. Fox, R.E., Exec. Engineer, Secunderabad Division,	377
Water Works, Report on the Ulsoor. By Lieut. F. J. Romilly, R.E., Exec. Engineer, Bangalore,	311
Water Works, Karandwad,	357
Water Works, Inchalkaranji,	375

LIST OF PLATES.

LITHOGRAPHS.	PAGE.
The South Pass Jetties of the Mississippi. [1 Plate], ...	1— 11
To find the Centre of Gravity of a Polygon graphically. [1 Plate], 	13— 14
Note on Experiments made to determine the true Co-effi- cient of the Discharge of the Head Sluice of the Midna- pore Canal. [2 Plates],	49— 61
On the Action of Falling Water. [10 Plates], 	63— 94
Inter-Oceanic Canal Projects. [1 Plate], 	103—124
Moveable Dams. [6 Plates], 	125—140
Report on the Iron Ore and Coal from the Chanda District of the Central Provinces of India. [1 Plate], 	185—221
Inter-Oceanic Canal Projects. [1 Plate], 	223—257
James Cleminson's "Flexible Wheel-base" or Radiating Axles. [1 Plate], 	259—262
Clip Calliper for lifting Waste Weir Planking. [1 Plate],	263—265
Electrical Inter-Communication in Trains. [1 Plate], ...	267—273
Alfred Nobel's Dynamite. [3 Plates], 	275—310
Report on the Ulsoor Water Works. [6 Plates], 	311—349
Water Supply, Ahmedabad. [2 Plates], 	353—355
Water Supply, Aden. [1 Plate], 	359—374

ALPHABETICAL INDEX.

A.	Page.		Page.
Action of Falling Water, On the, ..	68	India, Report on the Iron Ore and, ..	185
Aden, Water Supply, ..	359	Co-efficient of the Discharge of the Head Sluice of the Midnapore Canal, Note on Experiments made to determine the true, ..	49
Ahmedabad, Water Supply, ..	353	Comparative Working Expenses of Broad and Narrow Gauge Railways, Papers on the, ..	141
Alfred Nobel's Dynamite, ..	275		
Almora Water Supply, ..	351	D.	
Axles, James Cleminson's "Flexible Wheel-base" or Radiating, ..	259	Dams, Moveable, ..	125
		Discharge of the Head Sluice of the Midnapore Canal, Note on Experiments made to determine the true Co-efficient of the, ..	49
B.		Dynamite, Alfred Nobel's, ..	275
Broad and Narrow Gauge Railways, Papers on the Comparative Working Expenses of, ..	141		
		E.	
C.		Electrical Inter-Communication in Trains, ..	267
Calliper for lifting Waste Weir Planking, Clip, ..	263	Expenses of Broad and Narrow Gauge Railways, Papers on the Comparative Working, ..	141
Canal Projects, Inter-Oceanic, {	108 223	Experiments made to determine the true Co-efficient of the Discharge of the Head Sluice of the Midnapore Canal, Note on, ..	49
—— Midnapore, Note on Experiments made to determine the true Co-efficient of the Discharge of the Head Sluice of the, ..	49		
Central Provinces of India, Report on the Iron Ore and Coal from the Chanda District of the, ..	185	F.	
Centre of Gravity of a Polygon graphically, To find the, ..	13	Falling Water, On the Action of, "Flexible Wheel-base" or Radiating Axles, James Cleminson's, ..	63 259
Chanda District of the Central Provinces of India, Report on the Iron Ore and Coal from the, ..	185		
Clip Calliper for lifting Waste Weir Planking, ..	263	G.	
Coal from the Chanda District of the Central Provinces of		Gravity of a Polygon graphically, To find the Centre of, ..	13

INDEX.

II

	Page.		Page.
H.			
Head Sluice of the Midnapore Canal, Note on Experiments made to determine the true Co-efficient of the Discharge of the, ..	49	the true Co-efficient of the Discharge of the Head Sluice of the, ..	49
Hyderabad Subsidiary Force at Secunderabad, Descriptive account of the system of Water Supply by means of steam pumping for the European Troops of the, ..	377	Mississippi, The South Pass Jetties of the, ..	1
		Moveable Dams, ..	125
I.			
Inchalkaranji Water Works, ..	375	N.	
India, Report on the Iron Ore and Coal from the Chanda District of the Central Provinces of, ..	185	Narrow Gauge Railways, Papers on the Comparative Working Expenses of Broad and, ..	141
——, Enquiry into supply of Sleepers for, ..	95	Nobel's Dynamite, Alfred, ..	275
Inspection Notes—Panjab Railways, ..	15	Note on Experiments made to determine the true Co-efficient of the Discharge of the Head Sluice of the Midnapore Canal, ..	49
Inter-Communication in Trains, Electrical, ..	267	Notes, Inspection—Panjab Railways, ..	15
Inter-Oceanic Canal Projects, ..	{ 103 223	O.	
Iron Ore and Coal from the Chanda District of the Central Provinces of India, Report on the, ..	185	Oceanic Canal Projects, Inter-, {	{ 103 223
J.			
James Cleminson's "Flexible Wheel-base" or Radiating Axles, ..	259	P.	
Jetties of the Mississippi, The South Pass, ..	1	Panjab Railways—Inspection Notes, ..	15
K.			
Karandwad Water Works, ..	357	Polygon graphically, To find the Centre of Gravity of a, ..	13
M.			
Midnapore Canal, Note on Experiments made to determine		Projects, Inter-Oceanic Canal, {	{ 103 223
		Provinces, Central, of India, Report on the Iron Ore and Coal from the Chanda District of the, ..	185
		R.	
		Radiating Axles, James Cleminson's "Flexible Wheel-base" or, ..	259
		Railways, Papers on the Comparative Working Expenses of Broad and Narrow Gauge, ..	141
		—— Panjab—Inspection Notes, ..	15

	Page.		Page.
Report on the Ulsoor Water Works, ..	311	W.	
— on the Iron Ore and Coal from the Chanda District of the Central Provinces of India, ..	185	Waste Weir planking, Clip Cal-liper for lifting, ..	268
S.		Water, On the Action of falling, ..	63
Secunderabad, Descriptive account of the system of Water Supply by means of steam pumping for the European Troops of the Hyderabad Subsidiary Force at, ..	377	— Supply, Aden, ..	359
Sleepers for India, Enquiry into supply of, ..	95	— Supply, Ahmedabad, ..	353
South Pass Jetties of the Mississippi, The, ..	1	— Supply, Almora, ..	351
T.		— Supply by means of steam pumping for the European Troops of the Hyderabad Subsidiary Force at Secunderabad, Descriptive account of the system of, ..	377
Trains, Electrical Inter-Communication in, ..	267	— Works, Inchalkaranji, ..	375
U.		— Works, Karandwad, ..	357
Ulsoor Water Works, Report on the, ..	311	— Works, Report on the Ulsoor, ..	311
		Wheel-base " or Radiating Axles, James Cleminson's "Flexible, ..	259

LIST OF AUTHORS.

A.

Apjohn, J. W., Esq., 49.
Ashhurst, T. W., Esq., 351.

B.

Beresford, J. S., Esq., 63.
Buckley, R. Burton, Esq., 125.

C.

Carroll, E. B., Esq., M.I.C.E., 141.
Clarke, H., Lieut. R.E., 359.

E.

Editor, 1, 18, 95, 223.

F.

Fox, H. C., Capt. R.E., 377.

H.

Hackney, William, Esq., 185.
Hayes, A., Esq., 263.

M.

Medley, J. G., Col. R.E., 15.

Menocal, A. G., Esq. C.E., 103.
Morant, J. L. L., Major R.E., 275.

N.

Neville, J., Lieut. R.E., 353.

O.

O'Connell, J., Esq., 161.

P.

Pilkington, H., Lieut. R.E., 154.

R.

Rendel, A. M., Esq., 173.
Romilly, F. J., Lieut. R.E., 311.

W.

Winter, G. K., Esq., F.R.A.S., M.S.T.E.,
267.

—

•

•

•

•

•

•

•

•

•

No. CCCXVIII.

THE SOUTH PASS JETTIES OF THE MISSISSIPPI.

[*Vide Plate*].

BY THE EDITOR.

*Abstract of Article No. CLXXXIII., Vol. III., August 1879,
Transactions of the American Society of Civil Engineers.*

THIS paper by MAX. E. SCHMIDT, C.E., Member of the Society, is headed "Notes on the Consolidation and Durability of the Works, with a description of the Concrete Blocks and other constructions of the last year," and the author disclaims any discussion as to the question whether the jetties are the proper means by which to improve the navigation at the mouth of the Pass.

The Mississippi River, about 12 or 13 miles above its mouth, splits into three Passes. The South-West Pass, the South Pass, and the Pass a L'Outre, *vide Fig. 1*. Just above the head of these Passes the river gradually widens from 2,600 feet to 8,500 feet. As a result of this widening, there existed at this point a shoal common to all the Passes, which extended from one shore of the Mississippi to the other. The depths on the shoal were proportionate to the size of the Pass below the point, thus the South Pass, which discharged only about $\frac{1}{10}$ of the total volume, had the shoalest entrance, *viz.*, only 14 feet. The table under *Fig. 1* shows the chronological history of the works constructed for the improvement of the shoal. It was believed at first that the East Dyke alone would increase the depth of water at the head of the Pass to 20 feet. But it was found absolutely necessary to increase the depth over the shoal at the head of the Pass to keep pace with the deepening through the jetties at the lower end of the Pass, and the

further works became necessary. The mattress sills, which extend across the South-West Pass and the Pass a L'Outre, are simply submerged dams to guard against the scour caused by the other works. The works are apparently mattress jetties similar to those described hereafter in the extracts from actual article. The above is extracted from Appendix B. The article itself describes the construction of the works at the lower end of the South Pass, where the river really joins the sea, *vide Figs. 2 to 6*. I have as far as possible, consistent with the necessity for shortening the article, used the author's own words. I regret I could not print *in extenso*, but the extracts will, I believe, give a sufficiently complete account to be interesting.

The general plan of the work is shown in *Fig. 2*, and the following general description is partly an extract of the official report of the Board of Engineer officers appointed by the President of the United States, dated January 22nd, 1879, from Van Nostrand's Magazine for March 1879.

The original design was to construct, starting at marginal points on its banks above where the normal channel depth (30 feet) of the Pass itself begins to diminish, parallel jetties, extending thence to the deep water of the Gulf, thus confining the outflowing water in a channel of the same width as that of the Pass itself, and thereby prolonging the normal depth, 30 feet, through the bar and into the open Gulf.

The length required for the jetties was thus, *vide Fig. 2*, about 12,000 feet on the east, and 8,000 feet on the west. The average width between the banks of the Pass is about 700 feet, and this is fixed as the minimum between the jetties; but they are built parallel at 1,000 feet apart, with temporary wing dams, 150 feet long. The origin of the West Jetty was established about 600 feet from the west bank, with which it was connected by the work called Kipp's dam. The plan of construction was in its main features essentially that developed by long experience in Holland, on like yielding substrata, *viz.*, a broad foundation stratum of willows or other brush formed into mattresses, on top of which was built a superstructure, of tapering section, of alternate strata of mattresses and stone or gravel. The formation is shown in the sections. It was added to as subsidence occurred, till mean high water level was gained. This settlement appears to have varied for the shoal parts up to about 3 feet maximum. At the extreme ends of the jetties the subsidence was so considerable, that the terminal points were withdrawn 330 and

280 feet, and so terminate the eastern on the very edge, and the western 200 feet inside, of the old bar.

The tides are diurnal and rise $1\frac{1}{2}$ feet. The mean velocity of river in flood is 3 miles an hour, decreasing to $\frac{1}{2}$ mile at low water. The prevailing wind is easterly, and gales of 72 miles an hour have been observed.

The specifications state as follows:—

Of the East Jetty 8,000 feet, and of the west 9,000 feet, seaward, is to be finished, (*see Fig. 4.*) with a rounded pavement of rip-rap stone on top of the mattress work. The crest of the pavement to be $1\frac{1}{2}$ feet above average flood, and base 20 feet wide. In order to prevent leakage, gravel to be worked into the mattresses, and the top levelled up before proceeding with the paving.

The remaining distance of both jetties, 8,800 feet and 2,800 feet, to be consolidated by large blocks of cement concrete placed on top of the jetty, *see Fig. 5.* The blocks to be from 16 to 20 feet long, from 5 to 13 feet wide, and from $2\frac{1}{2}$ to 4 feet deep. The dimensions enlarging by offsets as the jetties approach the sea ends. The bottoms of the blocks to rest at the plane of average flood tide, the jetties being levelled up to that plane by large and small stone and gravel. The blocks to serve as a foundation for a superstructure parapet, to be composed of concrete, and continuously built, from 3 to 6 feet wide, and from $2\frac{1}{2}$ to 4 feet high. This parapet to be applied to the extreme 1,600 feet of both jetties. The parapet to be put on after settlement is complete. From the upper end of the concrete work to 600 feet from extreme end, the slopes of both jetties to be of rubble stone, slope 2 to 1. A rounded cap of paved stone to be carried from half the height of the blocks to the lowest attainable water edge.

For the lower 600 feet of both jetties, (*see Fig. 6.*) the sea slope to have a foundation of willow mattresses 100 feet wide and 2 feet thick. On this foundation a sloping palmetto pile crib-work to be placed and filled with stones, averaging one ton in weight. On the river side a similar crib-work to be sunk on the rip-rap foundation already in place. The vertical edges of the cribs to face the jetty 10 to 15 feet from the embankment. The intermediate space being filled with stone. Large rock to be used for covering the crib and connecting with the concrete blocks.

The T-heads are of somewhat similar construction.

The main points of the design are summed up thus—(1), That the

broad elastic foundation will prevent undermining; (2), That the slopes will resist the impact of the waves; (3), That the tight work will stop leakage; and (4), That work maintained at a uniform height will obstruct the escape of water by overflow. The first pile was sunk on 17th June, 1875, and the first willow mattress a month later. At the date of the article, *viz.*, August 1879, Mr. Schmidt writes, "The willow work may be regarded as completed, and the progress made towards consolidating the jetties by the application of heavier material, has advanced far enough to foretell the period when this work will be completed, to stand an enduring monument of the capabilities of our profession."

The proportion of stone used to willow was 1 to 5.32; and this though it appears small, was found sufficient. The specification for the willow was flexible branches not exceeding two inches at the butts. The willows grow abundantly on the river banks, and were brought about 25 miles. The stone was a much greater difficulty. 21,000 tons of ballast brought by foreign ships was altogether obtained in New Orleans, but this supply was soon exhausted, and after trying some quarries 550 miles distant from which the stone did not suit, the Contractors, Messrs. Sharp, McDonald & Co., brought the stone from quarries on the Ohio river, 1,300 miles above the mouth of the Mississippi. It is limestone, weighing 155 lbs. per foot. The work was much aided, and the Engineers enabled to adopt a less section, *see Fig. 3*, than originally contemplated by the vast deposit of sedimentary matter during the course of construction. Mr. Schmidt accounts for this as follows:—

It will be remembered that the entire length of the foundation of the jetties, from the lands-ends to sea-ends was laid, before the second tier was applied; and again, that the entire second tier was placed and sunk on the foundation, before the third tier was commenced, and so forth, until the surface was reached.

The jetties have therefore been raised with a uniform degree of vertical progress over their entire length.

In doing this, it was observed that each tier of mattresses caused a shoaling on the sea side corresponding in height with the thickness of the mattresses in place.

This was due to the obstruction which was placed in the way of each successive layer of current, stopping the flow sufficiently to cause the sediment to precipitate on the other side.

As the jetties grew up, and commenced to confine the volume of the Pass, the water was largely charged with additional sediment due to channel erosion. But, by limiting the potency of the current to the channel between the jetties, no suspending power existed to carry the load of sediment over that portion of the bar which was not jettied.

It was dropped therefore on the crest and on the landward slope of that bar, building up a chain of successive reefs, as the bottom neared the surface. New Pelican reef, Base-line reef, and Reef Extension, (*see Fig. 2,*) are such new formations.

The numerous advantages of the sea side deposit were fully appreciated, and measures taken to induce by means, based upon the same laws, a similar deposit on the river side.

For this purpose, a system of wing or spur dams was built, each wing dam jutting out 150 feet from, and at right angles to, the main line of the jetty. Although rapidly constructed, and with no view to permanency, these wing dams have been most effective in giving protection to the jetties and hastening channel erosion. The current is stopped above and below the dams; the sediment drops and a bank forms.

On *Plate XXXIV.** are two comparative sections of the channel between the jetties, *Fig. 1* showing the condition before, and *Fig. 2* the condition after, the wing dams were built. The effects are plainly visible.

The channel between the jetties, although intended to be 1,000 feet, is at present only about 700 feet in width; but while the channel depths are allowed to increase in proportion to the greater contraction of the channel way, the jetty embankments are removed behind a sheltering bank of deposit which is braced and stiffened, as it were, by the tilted mattresses composing the wing dams.

Of the entire length of the jetties, all but the last 2,000 feet at the extreme sea-ends have received these protective deposits on the river and sea-side.

It is evident from the plates and drawings presented, that 90 per cent. of the willow work composing the jetties is immovably bedded in the deposits of the river.

No such thing could have come to pass if the water of the Mississippi did not contain the vast percentage of sedimentary matter which it carries to sea annually. But in such a case there would have been no delta, no

* Not reproduced.

bar and no jetties. Thus, the sediment itself becomes one of the agencies in removing the deposits of centuries.

Mr. Schmidt then enumerates the points of design referred to above, and shows that the work provides for them entirely. With regard to the "sea-ends" which he defines as "the lower parts generally without defining limits," he states that as these lose the protection of the natural and artificial reefs, they are of course more exposed and more difficult to maintain than the rest: but as the money to carry on the works had to come from sources opened out by the success of the works themselves, the area of the section could only be increased gradually. Still the repairs, which from time to time became necessary, made it imperative that at the earliest possible moment such measures should be taken as would bring up the lower ends of the jetties to the standard of strength required for permanency. Two new elements were here introduced, unusually great subsidence and the attacks of the worms, and it was not till the fall of 1877, that after adding tier upon tier of mattress, the foundation was forced through the quicksands below, and struck a bed on the older, harder and firmer strata of bar deposit. Near the extreme end 16 tiers of mattresses were sunk, representing a vertical height of 27 feet of compressed willow work. The original depth at this place was 8 feet, so that 19 feet of the work are below the original bottom of the bar. This subsidence was very marked at the beginning, but more gradual at the end. The attacks of the worms were guarded against by coating the work at the sea ends with loose stone. The teredo does not attack wood where the free access of sea water is impeded.

With regard to the consolidation of the Jetty Mr. Schmidt writes:—

At the upper part of the work the sand and clay of the river has been so firmly imbedded in the mattresses, that very little additional compression is needed to make the work tight and permanent. But, as the jetties approach the sea end, and come in contact with the clean salt water of the Gulf, experience showed that the sediment, which had accumulated between the willows and stones during a high stage, would speedily be removed during the subsequent low stage of the Mississippi. As a result the river sustained a considerable loss of water by leakage and overflow, where the volume was needed most, to serve the purposes of channel making.

It has been estimated by careful simultaneous gauging that nearly 25 per cent. was abstracted from the volume passing the Lands-end at East Point, before it reached the mouth of the jetties. Of this loss the far greater part escaped through and over those portions of the jetties which extend beyond the sheltering protection of the reefs and shoals. It increased at the same ratio as the degree of exposure toward the sea-ends, and it became evident that compression by weight would be the only cure for the evil.

While the efficiency of rubble stone for consolidating the upper parts of the jetties could not be questioned, the requirements of weight and strength, sufficient to resist the shock of the waves at the sea-ends, could not be obtained from the largest sized rock, which it was practicable to bring from the distant quarries.

About two years ago, as an experiment, quantities of large rock, weighing from one to two tons apiece, were, at considerable expense, placed upon the lower ends of the jetties. But in a severe gale, which occurred a few months later, these rocks were lifted up by the waves, rolled over the jetty embankment, and deposited on the leeward slope, thereby adding, per chance, to the strength of that slope.

In selecting a material which would effectively consolidate the sea-ends of the jetties, it was important to bear in mind that gales along the Gulf coast are generally attended by high flood tides which have been observed to rise from three to four feet above the level of ordinary tides; these call into existence an enormous lifting power that can only be overcome by equipollent means of resistance.

For this reason, and in order to accomplish a permanent consolidation, something more powerful than quarried stone had to be resorted to. The plans of capping the last 3,800 feet of the East, and 2,800 feet of the West, Jetty, with blocks made of cement concrete, provide for an application of from 25 to 72 tons in solid blocks. Their dimensions have been so chosen as to impart great stability, and to dismiss at once all possibility of upsetting.

The largest blocks on record, are stated to be those used in the Cherbourg breakwater, weighing 44 tons, but in these jetties, by adopting the plan of making the blocks *in situ*, the smallest blocks used were 25 tons, and the largest 72 tons, excluding the parapet, which is to be built on the top. In perfecting the plans, the protection of the blocks by slopes has

been carefully considered. Single stones in considerable quantities have, from time to time, been used in protecting the lower part of the jetties; but during heavy gales the sea has been observed to carry these seaward by the receding action of the waves. In this manner the sea might have been slowly set at work to build up a slope of its own, but as such a process would have been slow and costly, an artificial slope was made with palmetto cribs. The palmetto is a species of palm tree. Its wood is highly fibrous and tough, and corky, and said to be impervious to the attacks of the teredo.

The construction of the sea and river slope by palmetto crib-work, as proposed for the lowest 600 feet of the jetties, was not commenced before the month of April of the present year.

Cribs are shown in section in *Fig. 6*. Some were as large as 50 feet long, 22 feet wide, and $5\frac{1}{2}$ feet high.

Before the dimensions of a crib are given to the carpenters, a careful investigation is made, embracing depth of water and condition of bottom, on and near the place where the crib is to be placed. Referring to the one on the drawing,* there are 51 palmetto piles each 22 feet long, which are placed in one row, one foot from centre to centre, on the inclined ways, formerly used for mattress building.

This being the floor of the crib, a second row, consisting of five logs is placed across and to break joints with the flooring at distances of 5 feet from centre to centre. In the same manner the third row is placed, consisting of 11 piles, $16\frac{1}{2}$ feet long, at distances of 5 feet between the centres, crossing and breaking joints with the lower row.

Augur holes are then bored, and the rows bolted to each other by one inch bolts. The fourth and fifth row of piles is then laid, as shown on the illustration, and drift-bolted to the lower layers.

The crib is braced by short logs standing upright against the corners of a cell. Their lower ends are flattened, and wedged tight between the flooring, where they are fastened by bolts. In addition to this, stirrup bolts are used at every alternate corner of a compartment, which tie all the logs from the bottom to the top. The compartments are four feet square in the clear, and large enough to admit the largest boulders that are brought to the jetties. The cribs are pulled off the ways and into the river by a tug, which takes them at once to the place for which

* Plate not copied, section is shown in *Fig. 6*.

they are built. Here a row of guide piles has been driven, about 10 feet from the jetty embankment, to which the vertical edge of the crib is lashed. The sinking may then take place. The compartments are finally closed by immense boulders, which are lifted into position by a derrick. The remaining space of about 10 feet in width, between the vertical edge of the crib and the jetty embankment, is filled with stone until it appears above water. At some of the cribs the flooring has been constructed of palmetto logs, split lengthwise through the centre, but it is quite immaterial to the strength of the crib; besides the labor involved in cleaving the logs, hardly justifying its constant application, it was only resorted to when the supplies ran short.

The following is the description of the mode of constructing the concrete blocks at the sea-ends.

The concrete mixer on each side was placed over the jetty proper. Alongside was a storage platform about 100' $\times$ 70' area, founded on 400 piles at intervals of 8 feet, connected by 5" $\times$ 14" caps and planked over. This was supplied with a wharf in the deep water, connected by a bridge portion about 60 feet long, to facilitate landing the material. The cement was housed at one corner of the platform, owing to the dampness of the climate; the other materials, sand, gravel and broken stone were just piled loose ready for use. The concrete mixer was placed over the jetty proper, and consisted of a 5 feet 9 inch cube, made of $\frac{1}{4}$ -inch boiler iron, well rivetted and held together by bands of flat and T-iron. This cubical box was suspended in a stout wooden framing, by two hollow cast-iron trunnions 7 $\frac{1}{2}$ inches diameter, rivetted to two *diagonally* opposite corners. The trunnions were 22 feet above high water, and the mixer was revolved by steam power. One corner of the box was cut off and furnished with a suitable lid to fill and empty by. The materials were brought dry to the mixer in hand carts, and raised the necessary 40 feet by a steam elevator. Water was supplied through the hollow journal, while the ingredients were being revolved; each charge had 22 revolutions, and was then discharged into dumping cars brought under the mixer, containing about 2 cubic yards, built of $\frac{1}{4}$ -inch boiler plate. The dumping was easily done almost automatically by ratchet wheels and wooden levers attached permanently to the axle on each end of the car. A rail track, on piles, was laid along each jetty 10 feet above flood at mixer 7 $\frac{1}{2}$ at sea end. The moulds for the blocks were constructed almost entirely

without nails or spikes. The bottoms of inch planks. The sides of 2-inch planks secured by plank cross-ties and battens. Each car of concrete was run from mixer to frame in about one minute; it was not rammed, only roughly spread by men in the frame. 2,700 cubic feet of concrete a day was found to be a fair average of the work on each jetty. When the mould was filled, the surface was roughly levelled with a rake, and allowed to set without further disturbance. Another mould was then commenced. Four days after setting, each block was coated on the upper surface with mortar of half American Portland cement, half sand. The box was then covered with inch boards, and not disturbed for two weeks; the moulds were then removed.

The blocks after removing the moulds, exposed generally a uniform surface. Irregular places and holes were plastered.

The concrete was made of broken stone, gravel, sand, and cement. The stone was passed through a 3-inch ring. The gravel varied from $2\frac{1}{2}$ to $\frac{1}{10}$ -inch in diameter. The sand was moderately coarse and sharp-grained; average diameter of grains $\frac{1}{10}$ -inch. The cement was Taylor's Portland, a slow setting cement, averaging 278 lbs. tensile strength per square inch in 7 days' setting. Essentially the proportional parts of the mixture were 15 parts volume broken stone, 4.38 gravel, 8.28 sand, 3.00 cement.

Mr. Schmidt concludes as follows:—

In regard to the construction of the parapet, it has not been decided yet, when it will be time to commence. The degree of subsidence displayed by the blocks will settle this point in course of time.

At present it may be too early, from the limited amount of observations, to discuss the probabilities involved in this question. It is clear, however, that the amount of compression, exacted by the tremendous weight of the blocks, will continue to act upon the elasticity of the subaqueous layers of mattresses, until the same is ultimately destroyed.

A complete record, ascertained by careful and frequent periodical levelings, is kept of each block, and the elevations are compared with the original plane, at which the blocks were set.

There seems to be a general tendency, on the part of the blocks, to settle within the first ten days of their construction, and then to remain stationary or nearly so for an indefinite period.

The impetus imparted by the sudden application of so great a weight is evidently the cause of this action.

The subjoined Table is given to further illustrate this subject.

TABLE.

Showing Subsidence of Concrete Blocks, at different periods, on East Jetty.

Number of contiguous blocks from which average is taken.	Net weight of mass of concrete under consideration, in tons of 2,000 lbs.	Initial elevation of top of blocks above average flood tide.	Date when placed.	Date when levels were taken.	Elevation above average flood tide of those dates.	Elevation above average flood tide on June 11th.
	Tons.	Feet.			Feet.	Feet.
4	110	3.00	Feb. 2	Feb. 10	2.685	2.480
4	136	3.00	" 12	" 20	2.440	2.140
4	136	3.00	" 18	" 20	2.790	2.600
4	150	3.00	" 24	Mar. 4	2.605	2.415
4	150	3.00	Mar. 4	" 14	2.610	2.406
4	193	3.50	" 8	" 14	3.351	3.150
4	193	3.50	" 11	" 25	3.440	3.328
4	288	3.75	" 15	" 25	3.533	3.373

The final note to the article by the Editor of the Transactions is as follows :—

Since the presentation of the above paper at the convention at Cleveland, the following official information has been secured, and is added to complete the record.

On June 18th, 1879, a channel of 26 feet in depth, and at no point less than 200 feet wide, was obtained through the jetties.

On July 8th, 1879, a channel of 30 feet in depth, without regard to width, was obtained through the jetties.

On July 10th, 1879, a navigable channel of 26 feet in depth was obtained at the head of the Pass, connecting the deep water in the Mississippi with the deep water of the South Pass.

Thus, in less than four years from the day on which work was begun, the final result aimed at has been accomplished, and there exists now at the mouth of the Mississippi a channel which will constitute the greatest commercial highway in the world.

A. M. B.

—

FIG.



(1)



2

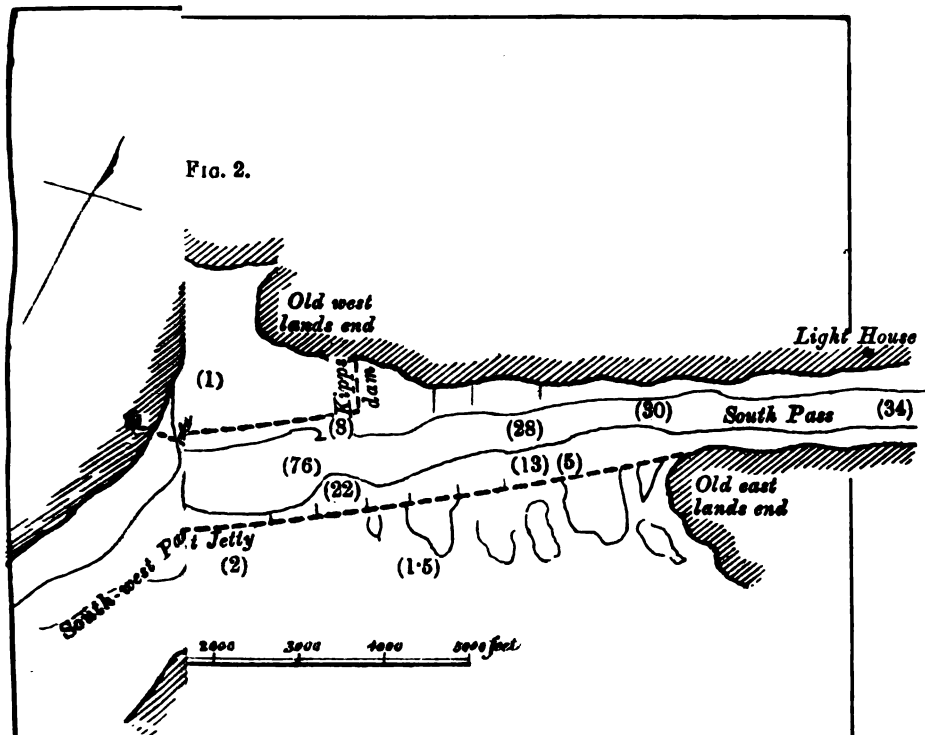


FIG. 4.
SECTION JETTIES AS ORIGINALLY PROPOSED.

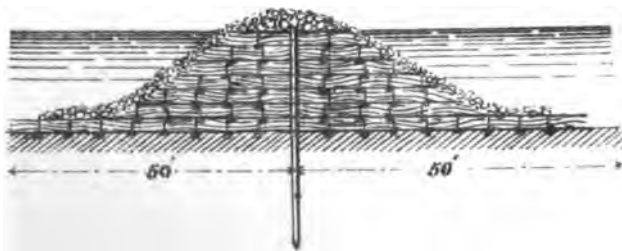
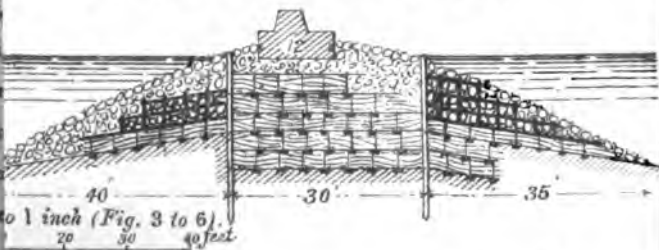


FIG. 6.
SECTION 11,800 FEET FROM EAST POINT.



No	Name of
1	East Dyke
2	Dam, 1,
3	Lighthouse
4	Island Dyke
5	Lighthouse
6	South-West
7	West Dyke
8	Island Dam
9	Island Dyke
10	Pass a L'O
11	Upper Dam
12	Island Dyke

Litho. T. G. Press, N.

THOS. D. BONA, Sup.

—

FIG.



a

—

—

—

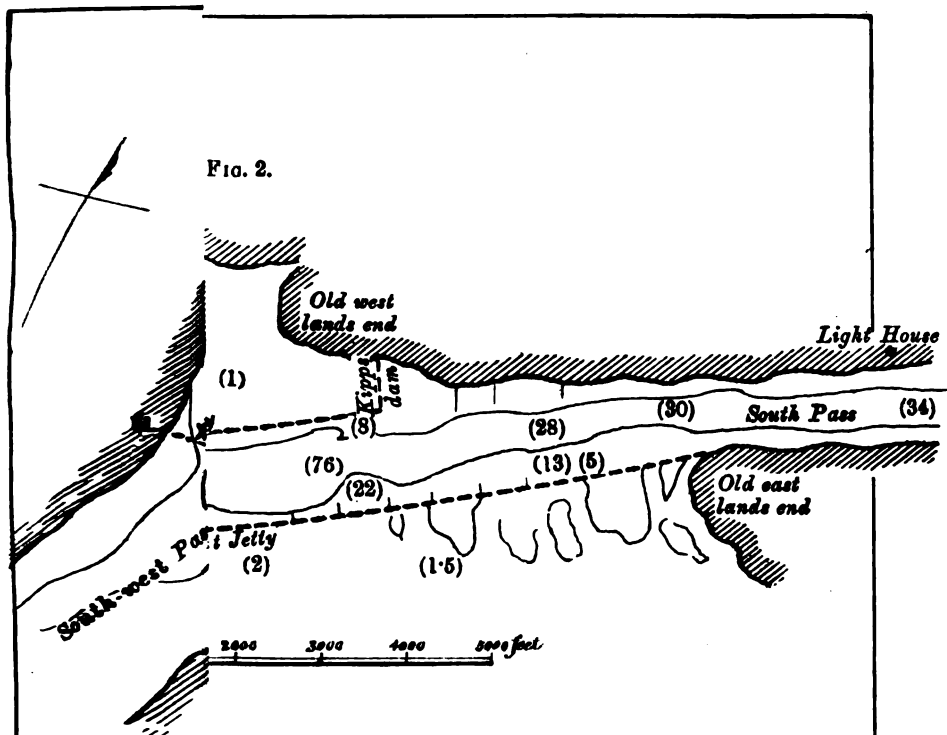


FIG. 4.
SECTION JETTIES AS ORIGINALLY PROPOSED.

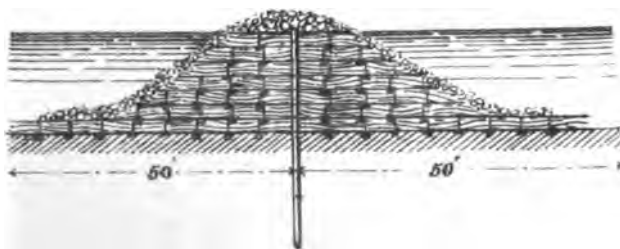
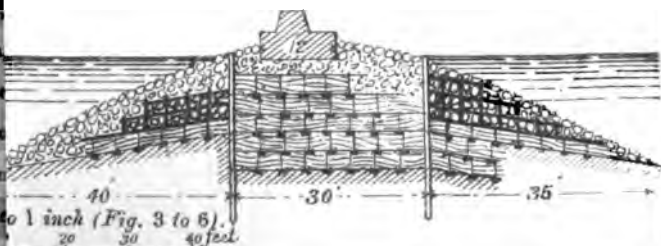


FIG. 6.
SECTION 11,800 FEET FROM EAST POINT.



No	Name of
1	East Dyke
2	Dam, 1,
3	Lighthouse
4	Island Dyke
5	Lighthouse
6	South-West
7	West Dyke
8	Island Dam
9	Island Dyke
10	Pass a L'O
11	Upper Dam
12	Island Dyke

Litho. T. O. Frost, Jr.

THOS. D. BONA, Supdt.



No. CCCXIX.

TO FIND THE CENTRE OF GRAVITY OF A POLYGON
GRAPHICALLY.

[*Vide Plate*].

BY THE EDITOR.

THE following method is given by Mr. T. Woodbridge Davis, C.E., in the October Number of Van Nostrand's Engineering Magazine. He calls it a new method, and as it may come in useful, I extract a short description of the process.

Mr. Davis points out that if the polygon be divided into triangles by diagonals from any angle, the centres of gravity of these triangles, and the middle points of the sides, are similarly situated with respect to the angle; and thus to find the centre of gravity of a quadrilateral, say as ABCD, *Fig. 1*, instead of finding the centre of gravity as G and G' of each triangle, and dividing GG' in R in inverse proportion of the areas of the triangles in R, we may better divide gg', the line joining the middle points of the sides, in the same proportion in r, and take R, the real centre of gravity, two-thirds of Ar from A.

The advantages of this method are that the work is less, and the scale larger. As also the triangles are as NB : ND or as ng to ng', the proportion is on the line to be divided, and it is only necessary to mark off length ng from g', as g'r, to give r. This Mr. Davis calls to *reciprocate* the segments; or even the line gg', for shortness.

To extend the method to any polygon, imagine another triangle AED added to make a pentagon as *Fig. 2*. Now r being found as before, it is only necessary to join rg', and divide it in r' in the proportion of the triangle AED and quadrilateral ABCD, and take R' at two-thirds A'r'. The division of g'r is done by reducing the quadrilateral ABCD to a

2 TO FIND THE CENTRE OF GRAVITY OF A POLYGON GRAPHICALLY.

triangle on base ED produced, *i.e.*, same base as triangle AED. The areas of the figures are then as their bases. First then side DC, as *Fig. 3*, produced to meet line parallel to diagonal AC in *a*, gives triangle $ACa = ACB$, or adding ADC, triangle $ADa = \text{quadrilateral } ABCD$, and again side ED produced to meet line from *a* parallel to diagonal AD in *b* gives triangle $ADb = \text{triangle } ADa \text{ or quadrilateral } ABCD$. The line $g''r$ has then to be divided in inverse proportion to the bases ED and D*b*, or $g''D$ and Dh the half of *Db*. Reciprocate $g''h$, *i.e.*, mark off length hD from g'' to *k*, and draw kr' parallel to hr . Then is $g''r$ divided in r' in the correct proportion, and R' may be at once located. For a hexagon the process is only adding as it were another triangle AEF, *Fig. 4*. FE produced to meet line from *b* parallel to diagonal AE, gives the proportion $g''E$ and El , the half of Ec . Reciprocate $g''l$ to *m*; draw mr'' parallel to lr' , and r'' is found, and so on for any number of sides.

The author points out that it is often convenient with a many sided figure, and saves accumulation of error, to commence from both sides, and work round both ways, instead of all one way as in above example.

For a quadrilateral there is very little construction; for a pentagon the line $g''r$ may be found as in *Fig. 2*, in which the centre of gravity must lie; a similar line may then be found joining the centre of gravity of quadrilateral AEDC, say *q* and *g*, in which also the final centre of gravity must lie, and the intersection of these lines will be it; and other adaptations of the method would no doubt strike any one using it.

A. M. B.

TO FIND THE CENTRE OF GRAVITY OF A POLYGON GRAPHICALLY.

FIG. 1.

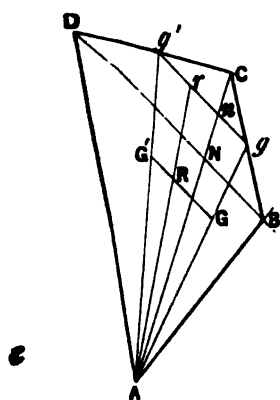


FIG. 2.

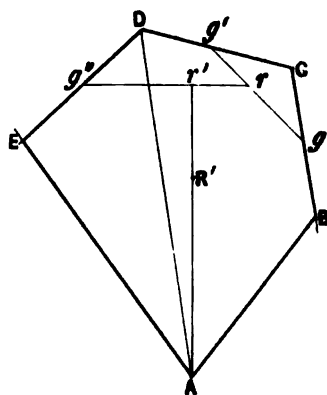


FIG. 3.

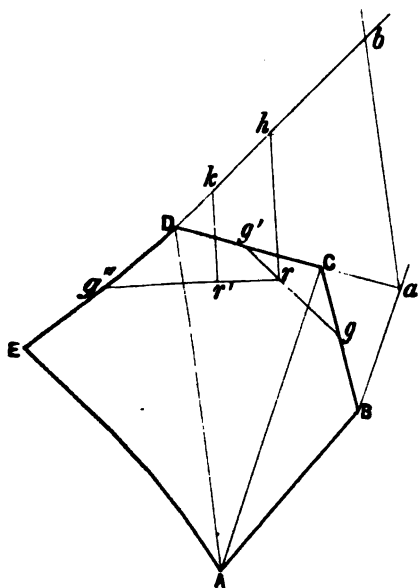
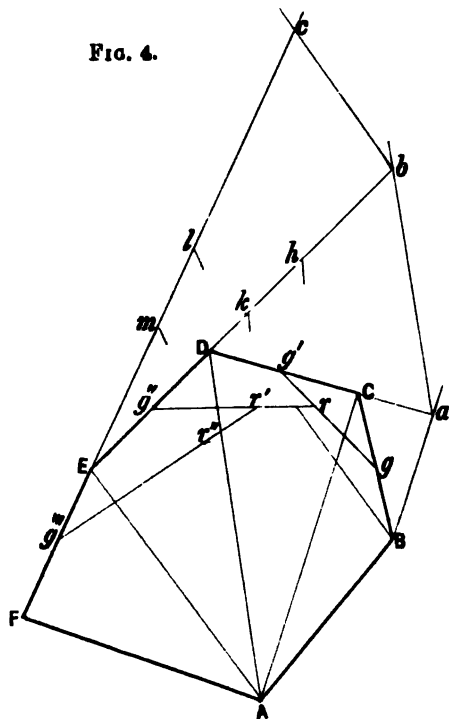


FIG. 4.



No. CCCXX.

INSPECTION NOTES—PANJAB RAILWAYS.

By COL. J. G. MEDLEY, R.E., *Consulting Engineer for Railways.*

	PAGE.
1. Lower Section, Indus Valley State Railway,	1
2. Empress Bridge, Adamwahan,	10
3. Memo. by Mr. Bell, Superintendent of Works, Sutlej Bridge, ..	12
4. Table of Bridge Tests,	16
5. Indus Steam Flotilla,	18
6. Hardwar Pilgrim Traffic,	24
7. Beas Bridge and East Beyn Valley,	27
8. Sutlej Bridge,	33

Report of Inspection of the Lower Section of the Indus Valley State Railway from Sukkur to Kotri.

Dated Lahore, 28th July, 1878.

THIS report, like that before submitted on the Upper Section, will be arranged under the headings given in Section I. of the Rules for Inspection of Railways, as laid down in Public Works Department Circular No. 23 of 11th November, 1875.

I will add some notes on the arrangements for crossing the Indus at Sukkur, and on a few other points which occur to me.

I. *Embankments and cuttings.*—The line from Sukkur to Kotri is almost wholly in bank from 5 to 15 feet in height. The only cuttings of any consequence are those at Sukkur between the main and river side stations, and those between Sehwan and Laki. The former are short in length, through sound rock, and not likely to give trouble. The latter

are heavy works, and one (known as No. 2) is not yet completed, the line being carried round by a diversion curve (750 feet radius). This cutting when finished will also not be troublesome to maintain.

Laki cuttings.—Some portion of the other Laki cuttings, are however, in very friable soil, and after heavy rain obstruction is likely to be caused by detached masses of rock falling from the top. Considerable provision has been made for the cross drainage at this point since the experience of the floods of 1876, but special precautions will have to be taken along the length between Sehwan and Laki (10 miles) with its numerous curves and steep gradients, and a vigilant system of inspection and watching should be enforced whenever heavy rain occurs.

Side slopes.—The slopes of the embankments are generally 2 to 1, and the banks themselves appear generally well consolidated.

II. *Curves.*—The only sharp curves on the line are the one above mentioned at the Laki Pass diversion of 750 feet radius, and the one leading to the Sukkur river side station of 755 feet radius. Both of these may be said to be temporary, as the latter will be superseded whenever the Indus bridge is constructed.

Gradients.—The heaviest gradient is a very short one, 145 yards only in length of 1 in 75 on the Sukkur river side line. There are, however, several others of 1 in 150, chiefly at the Laki Pass.

III. *Permanent way.*—The permanent way (like that in the Upper Section of the line) consists of a single headed flat footed wrought-iron rail of 60 lbs. to the yard, fished at the joints, and spiked down to transverse wooden sleepers (deodar or English creosoted pine). Fang bolts or coach screws are substituted for the spikes at the joints, although this has not yet been entirely done.

Ballast.—With regard to ballast, the Kotri Division has been entirely completed; the Sehwan Division is practically so. The Mehur Division has about half its length laid with surface ballasting; the other half has none. The Larkana Division has three-fourths of its length entirely unballasted.

The ballast is chiefly of stone of a good quality and size; the rest of brick.

IV. *Structures.*—The structures on the line, whether bridges or buildings, are of brick, and are of invariably excellent quality so far as I could perceive. I questioned the Engineer-in-Chief as to the probability

of the brickwork disintegrating (as has occurred in some of the Scinde, Punjab and Delhi Railway buildings at Kotri) owing to the presence of salts in the soil; but Mr. Rayne informs me that special precautions had been taken on this point by overburning the bricks, which he had reason to believe would effectually prevent this danger.

V. *Waterways*.—The waterways on this section are either for spill floods from the Indus or over irrigation canals from that river, or over nullahs (or naees) from the hills; a certain number of the bridges are brick arches of 20 feet span, but the great majority are wrought-iron girders of 20 and 40 feet span, precisely similar to those in the Upper Section; a few of these were carefully tested; also a Warren girder bridge of 60 feet span at Larkana, and one of 12-metre girders with the top flange strengthened. The results are given below.

Results of Bridge Tests.

On all (except the Warren girder at Larkana) the only test I considered necessary was observing the deflection and oscillation under an engine of the heaviest class crossing at a speed of 30 miles per hour. The deflection was ascertained by a wooden piston, which was pressed down into a cylinder supported on a staging below the centre of the girder, the upper surface of the piston being pressed up against the bottom of the girder before the passage of the engine. The oscillation was noted by the square top of the piston being covered with wet paint, the lines of junction with the girder while at rest being marked with a pencil on the latter.

In the case of the Warren girder, 2 openings, each of 2 girders 60 feet span, 2 engines head to head were put over each opening in succession, left there for 10 minutes and deflection noted. The deflection and oscillation at speed were then tested.

- (1). Ruk bridge, 13 40-foot girders { Deflection of 2 spans taken, $\frac{7}{16}$ "
{ Oscillation " " $\frac{1}{8}$ "

- (2). Larkana bridge over Ghar—
 2 spans, each 60 feet, Warren girders.
 After 10 minutes, S. girder down-stream 3".
 " " N. " " 3".

LOWER SECTION, INDUS VALLEY STATE RAILWAY.

Recovery complete.

At speed S. girders, D. $\frac{3}{4}$ " ; O. $\frac{1}{4}$ ".

„ N. „ D. $\frac{5}{8}$ " ; O. $\frac{1}{8}$ ".

-
- (3). Trough girder, span 25 feet—
D. $\frac{1}{2}$ " ; O. $\frac{1}{8}$ "

-
- (4). Bridge over W. Narra, 4 40-foot girders,
16-metre land span—
40 feet D. $\frac{1}{4}$ " } Oscillation insignificant.
6 metre D. $\frac{3}{16}$ " }

-
- (5). Kara Fitta bridge, 5 12-metre spans, top strengthened—
D. $\frac{3}{8}$ " ; O. $\frac{1}{8}$ ".

-
- (6). Aral bridge, 8 40-foot girders—
D. $\frac{3}{8}$ " ; O 0.

-
- (7). Dádaji bridge, 5 20-foot girders—
D. $\frac{5}{16}$ " ; O. $\frac{1}{16}$ ".

-
- (8). Ghari Wari Nai bridge—
2 35-foot skew arches, angle of skew 60°, of brick and stone,
noted for good work.

-
- (9). Bridge between Manjhand and Gopang—
12-metre opening: D. $\frac{1}{2}$ " ; O. $\frac{1}{4}$ ".

-
- (10). No. 85 bridge, 56-metre girders—
Unstrengthened: D. $\frac{5}{16}$ " ; O. $\frac{1}{16}$ ".
Compare this with (4), (5) and (7).

The piers of all these bridges are of brickwork, either on wells or of solid masonry on concrete.

As to the sufficiency of the waterway provided, it is enough here to say that the amount has been fixed after several years' experience, and has been added to from time to time, especially since the heavy floods of 1876. But experience also goes to show that this (generally) rainless country is subject from time to time to rain-floods of exceptional violence, and damage from this cause must occasionally be expected; nor does it seem possible (judging by the experience on the Kotri and Karachi Line) to make due provision for these by any calculations that would not be thought altogether extravagant.

VI. There are no parapets or hand rails on any of the bridges.

VII. There are no tunnels on the line. In the case of the long viaducts, the ends of the piers are accessible as a means of escape.

VIII. *Standard dimensions.*—There is no infringement of standard dimensions in any of the fixed structures.

IX. *Bridge platforms.*—The girder bridges are open, and have no platforms. The timber bed-plates are in some cases plastered with mud to protect them from fire. This is not a good arrangement, as there is danger from white ants, and all are, I understand, to be protected by thin sheet-iron or ballast.

X. *Fencing.*—The line may be said to be practically unfenced; on a few miles here and there where water is available kikar hedges have been sown, and are thriving; a few of the station plots have been fenced in by wire with tarred wooden standards. On a short length mud walls have been erected (experimentally I believe) on the slopes of the embankment.

Danger of unfenced line.—The chief danger (as on the Upper Section) of an unfenced line is when the surrounding country is flooded, and the Railway bank may become a place of refuge for animals; but with cow-catchers to all the engines the danger will be reduced to a minimum.

XI. *Level crossings.*—The kacha approaches to the level crossings have been completed, but no gates have as yet been provided; at the lower end the permanent houses for the gate-keepers have been built, elsewhere there are temporary huts.

XII. *Gradient posts and mile-marks.*—At the lower end of the line below the Laki Pass, gradient posts and mile-marks have been put up; on the rest of the line they are generally wanting.

XIII. *Points and crossings.*—The points and crossings are all on the standard pattern.

Locked points.—The following sidings should have locked points :—

Gurning brick-field ; (this will probably be taken up.)

Phulji river side branch.

Amri ; (this will probably be taken up.)

XIV. *Blind sidings.*—Blind sidings are, or will be, provided at all stations on the standard pattern.

XV. *Signals.*—The signals are all of the standard pattern, and have, most of them, been erected. Those that are still deficient are noted under the head of stations.

XVI. *Platforms.*—The platforms where built are 600 feet long, 20 feet wide, and ramped at both ends. The stations where platforms are still wanting will be found noted below ; most of those already made require metalling, and I strongly recommend that no station should be allowed to be without one. It is not safe with the ordinary pattern carriages, and at night is almost certain to lead to serious accidents.

Crossing arrangements at Sukkur.—The line to Rohri* comes down by a sharp curve and steep gradient (as mentioned in former report) to the river side station, and here in the flood season passengers and goods may walk or be carried from the platform on to the steamer.

But in the cold season the deep channel is some distance from the wharf, and I originally proposed a pile pier running into deep water with a pier head along which the steamers could lie.

This, however, has not been carried out, probably from fear of the piles being scoured out, but another line of rails has been carried along the bank upwards to Suttian island, the intervening channel being crossed by a stone bund.

At Suttian there is always deep water, and this will be the cold weather station, but the space is restricted, and the curve of approach so sharp, that the broad gauge rails cannot be laid, and a 1 foot 9 inch gauge pair of rails has been substituted, simply to save portage.

On the opposite or Sukkur side of the river, a river side station has been formed some little distance below (and close to the Indus Flotilla Steamer Wharf) where there is a platform, ticket office, two small waiting

* The ground about the Rohri river side station is in a most unsanitary state. An adjoining grove of date trees possibly screens the filth that gives rise to the stench. If this cannot be kept clean, it should be cut down.

rooms, and where it is intended to construct a large open shed. It is said there is deep water generally at this point, so that the steamer can come alongside, but there can be little doubt that this deep water cannot always be depended on, and when this is the case, a pier of some sort will be necessary.

A more favorable spot, at any rate for the cold season traffic, which was, I believe, originally proposed, was at a point somewhat higher up, just under the present Sindh Horse Club. Here, as at Suttian, there is always deep water, and although there are occasional eddies, it would appear they can be easily remedied by a little blasting of rock below. The line to this point would approach by a good curve if carried through the still water, as could easily be done on a stone bank.

I believe an objection was made to giving up this side by the Sukkur Municipality on the ground of general inconvenience; but if the road cut behind the hill for the railway were given up to the public, there would be no interruption of public traffic, and the Railway would have its own wharf.

At the present river side station, as wherever the line comes on to the river, I feel sure this will have to be the case. It will be quite intolerable to have a public road running between the wharf and the station, or through what will actually be the station yard; and if the present site is retained, the public traffic will have to be carried right round in rear of the station.

The present arrangements are so far advanced that they had better stand. The experience of a year's working will, no doubt, suggest what alterations are desirable.

For the actual passage of the river, the Railway proposes five barges of sorts and a steamer (which I did not see) now under repair at Adamwahan. It is also proposed to hire or purchase the *Ravi* steamer from the Indus Flotilla; this vessel was lying at Sukkur when I was there, but had not yet been tried; the Captain, however, evidently did not like the idea of working across to Suttian at this time of year, owing to the great strength of the current which he said would render it impossible to move alongside the wharf.

XVII. *Rolling Stock*.—The list noted below shows what rolling stock is at present available or expected for this section of the line. I saw one of the new Dübs' engines (with outside cylinders and on bogies) which appear to be very powerful and efficient.

Engines,					
"	tender,	..	..	..	6
"	new I. S. R.,	..	..	..	6
					1 running, 2 erected, 3 arrived, but not yet erected.
Passenger carriage, 1st class,					1
					Borrowed from E. I. R.
"	"	"	"	..	5
"	"	2nd	"	..	8
"	"	3rd	"	..	25
	Brake-vans,	..	..	..	14
	Horse-boxes,	..	..	..	9
	Timber and carriage trucks,	..	..	..	6
	Powder vans,	..	..	..	2
Goods covered wagons,					100
	Low-sided,	..	..	..	26
	Ballast,	..	..	..	20
	Rail trucks,	..	..	..	100
					These are covered wagons without the sides and top.
	Brake-vans,	..	..	..	4
					Temporary, made out of low-sided wagons.

I also saw some of the new 1st class carriages being constructed at the Karachi shops, and cannot but regret that so uncomfortable and obsolete a pattern should be approved. The retiring rooms at the end effectually prevent good ventilation; they should be in the centre of the carriage, which should at least have large end windows, though I should regard an end door with outside platform as a *sine quâ non* on this line.

It is certainly a pity that on this long line, where comfort and convenience to all classes of passengers are specially desirable, the best patterns of carriages were not carefully designed and made up in time. The trains now running on the Rohri section look as if made up of all the old worn-out carriages picked up from half the Railways in India, and such a state of things is hardly creditable to a Government line, which both in this, as in all other points should, I submit, set an example to the Guaranteed lines, by whose experience they should have been able to profit.

Neither in the matter of rolling stock or stations can this be said to have been done by the Indus Valley State Railway, and I cannot think the saving effected by it can have been of great importance.

My experience on the Scinde, Punjab and Delhi Railway has certainly

been that if a Railway is expected to pay, money is well laid out in providing liberally for the convenience of traffic and comfort of travellers, and I think other Railways would show the same results.

XVIII.—All the engines are or will be fitted with cow-catchers, and this should be rigidly enforced.

XIX.—I recommend, as in my former report, that during the hot season the number of passengers carried in a 3rd class carriage of the ordinary pattern should be reduced from 50 to 40 as a maximum.

I hope too that the system of running with unlocked doors will be adhered to. It is better that occasionally a careless passenger should be injured or even killed, or a fraudulent passenger should occasionally evade payment of his fare, rather than that the great bulk of passengers who are *not* careless or fraudulent should be locked up like sheep in a pen to their serious inconvenience and possible injury to health or life. Of course all platforms should be railed in.

XX.—The line will be worked by the ordinary 'line clear' system by the Electric Telegraph.

It will be seen from this report that the line is still far from complete, and that a considerable expenditure will be required before it is provided with even the most usual and necessary appliances for traffic.

The fencing is not begun; ballasting is only partially done; the accommodation at stations is of the most meagre description; signals and watering arrangements are in many cases deficient, though these, I understand, will shortly be supplied.

Moreover, the experience of the older lines amply shows that as traffic increases, fresh necessities arise, and that they must be provided for if the line is to pay.

The deduction I would draw from this is that the constructive staff of the line should be very cautiously reduced, for there is at present, and will be for some time to come, ample work for every man now employed. And this is all the more necessary on a line where the bad climate renders it essential that there should always be spare men available to replace those absent on leave or from sickness.

Having made my inspection at the very hottest time of the year, I can speak with some feeling as well as authority on this point, as also on the absolute necessity of extra care being taken to ensure the comfort and health of the working staff of the line as well as of the passengers, and I

sincerely hope that Government will deal very liberally in this matter.

In all essentials the line will be ready very shortly; and I recommend that it should be opened for traffic as soon as the deficient platforms, signals and watering arrangements are completed, the necessary rolling stock supplied, and the traffic staff engaged, the speed being for the present limited to 15 miles an hour including stoppages.

EMPRESS BRIDGE, ADAMWAHAN.

Note on Official Inspection of the Sutlej Bridge at Adamwahan, on the Indus Valley State Railway.

Dated Lahore, 29th May, 1878.

Mr. Bell's memo. herewith forwarded prevents the necessity of my giving any description of the bridge.

I began the inspection on the afternoon of Wednesday, the 22nd May.

As there were 16 spans, all of which it was desirable to test, I arranged to observe the deflection under the test load of the eight spans on the Bahawalpur side myself, Colonel Bonus, R.E., Engineer-in-Chief, Punjab Northern State Railway, who was with me, kindly consenting to do the same for the eight spans on the Mooltan side.

For the former eight spans a train of three engines and tenders, with five trucks loaded with stone in front and the same behind, was employed; the total weight on the span was 254 tons on a length of 260 feet, or very nearly 1 ton per foot run.

This train was brought over each span in succession, and the deflection of each girder noted—1st, when the train came to a stop; 2nd, after an interval of 10 minutes; 3rd, after the train had rolled off again.

For observing the deflection two parallel vertical deal rods were employed—one fixed to the lower flange, the other supported on the ground or fixed in the water. By ruling fine pencil lines across the parallel rods, the deflections to the $\frac{1}{16}$ th of an inch could be noted with great accuracy, and were judged to the $\frac{1}{32}$ nd of an inch.

For the other eight spans, as stone trucks were not available, a train of five engines (three tank engines and two with tenders) was employed; though this did not quite cover the whole span, it was really a severer test than the other.

The results under both trains were, however, singularly uniform, as

will appear on reference to the table, the deflection in no instance exceeding $1\frac{5}{8}$ th, and being generally under that, while the set in one instance only amounted to as much as $\frac{1}{8}$ th of an inch.

On the following morning, the train of five engines was passed slowly over the bridge from end to end, and the deflections noted by pencil diagrams. The results are recorded; they do not differ sensibly from those under the former test.

On this morning I visited the protective bund, and, passing slowly over the bridge on a trolley, examined the details of the work as far as possible.

In the evening the train of five engines was driven over at speed, and the oscillation noted of three of the girders, including the one last finished, which the roadway plates were not completely rivetted, and which was therefore likely to show the most unfavorable results. I took the observation on this myself with the vertical wire of a spirit level which was directed on a card divided to $\frac{1}{16}$ th of an inch, fixed laterally to the lower flange. The result of several observations showed a mean oscillation of $\frac{3}{16}$ ths of an inch only, the girders observed by Colonel Bonus showing $\frac{2}{16}$ ths. The deflections under the fast train, as shown by diagram, were 1.4 and 1.8 on the same girders.

The result of the above tests being so completely satisfactory, I did not think it necessary to pursue them further.

I compute the strain on the centre of the upper and lower flange of any girder produced by its own dead weight of 460 tons and a uniform live load of 250 tons as amounting to $2\frac{1}{2}$ tons per square inch in compression and 3 tons in tension, respectively.

I am of opinion that the speed of trains over the bridge need only be limited by the ordinary speed over the line, so soon as the roadway is quite finished; at present the rails follow the camber given to the girders, but they will, I understand, be lifted and packed to a level.

The covering plates of the roadway were intended, I believe, to be laid with asphalt; this has not yet been done, and it is, I understand, under consideration to cover them with concrete; this, if laid to a sufficient thickness over the crown of the cover plates, will bring a considerable extra weight on the roadway which it would be as well to avoid if possible.

It certainly seems a pity that the top of the girders cannot be utilized

for a carriage roadway; but the cost of the necessary approaches a present appears to put it out of question.

The ends of the earthen approaches where they join on to the abutments are at present very rugged, and should be finished off as soon as possible. I am not certain whether there will not be some trouble with the masses of loose stone here proposed.

It may be as well to have fixed marks on each pier which can be observed through a level from either shore during and after heavy floods. In spite of the great depth to which the well foundations have been sunk, it is still possible that subsidence may occur.

I think the protective spur bund is likely to answer well, judging from the experience obtained by the Scinde, Punjab and Delhi Railway on the Sutlej, Beas and Jumna, where similar groynes have certainly done good service, and I think it will not be found necessary to continue the spur right on to the abutment. But I certainly think the stone protection should be extended backwards over the crossing of the Naurangawāli, and I believe the Director concurs in that view. I should also object to the continuous channel along the toe of the present bund. If the river did take a set in that direction during a period of high flood, the safety of the bund would certainly be endangered by any scour along its upper side.

At present there is no sign of any action of the river which would threaten the right abutment or approach; but, as I believe Adamwahan itself (which stands on this bank) was inundated only a few years ago, it is quite possible that protective works may be required on this side also, and common prudence will dictate the maintaining of large reserves of stone on both banks for some years to come.

Although not strictly within the sphere of my report, as I happened to see this bridge little more than a year ago when the foundations were still unfinished, I cannot help bearing my testimony to the extraordinary energy and skill which must have been shown by the officers concerned in completing this great work under circumstances of considerable difficulty in so short a time.

Memo. by MR. BELL, Superintendent of Works, Sutlej Bridge, for the Consulting Engineer, who inspects the Sutlej Bridge.

There are 16 spans of 250 feet clear.

The foundations of abutments and piers are all alike, and each consists of three wells in a line of 18 feet 9 inches diameter with deodar timber curbs.

The steining is corbelled inwards from 2 feet 9 inches thick at the top of curb to 5 feet 3 inches at 13 feet 6 inches up. The internal space from the cutter bar of curb to 16 feet above is filled with hydraulic concrete.

Above this concrete the core hole 8 feet 3 inches diameter is filled with sand saturated with water to within 12 feet of low water level, and this 12 feet space is occupied by 9 feet of hydraulic concrete and 3 feet of masonry.

Externally the wells are cylindrical from the curb up to 10 feet below low water, from which point the centre wells are corbelled out to a square, and the outer wells similarly corbelled on their inner sides only.

The spaces between the wells are filled with concrete for 5 feet below low water.

The mean levels, subject to a variation of a few inches between one well and another, are as follows:—

Cutter bar, ...	...	...	265.50	above M. S. L.
Top of curb, ...	...	...	268.75	" "
Throat of steining, ...	...	...	282.00	" "
Top of concrete, ...	...	...	286.00	" "
" sand filling, ...	...	...	357.00	" "
Outer corbelling, ...	...	...	359.00	" "
Top of inner concrete, ...	...	...	366.00	" "
" well and low water, ...	...	...	369.00	" "
" plinth, ...	...	...	372.50	" "
Floor level, ...	...	...	380.00	" "
Roller bed stone, ...	...	...	395.00	" "
Fixed bed stone, ...	...	...	396.16	" "
Soffit of girder, ...	...	...	399.00	" "
Rail level, ...	...	...	403.50	" "
Underside of top cross girders, ...	...	...	422.00	" "
Top of girders, ...	...	...	425.50	" "

The stratum consists of sand entirely for the first seven piers from Adamwahan; the next three piers average two-thirds in sand and one-third in clay; and the last seven are or were fully two-thirds of their length in clay soil.

The protection of each abutment pier along with that next to it consists of a pier-shaped mass of three-and-a-half to four lakhs of cubic feet of stone, which is designed to withstand any possible effort of the river to undercut it. The centre line of this mass is occupied by a curtain of block

wells 9 feet square and 30 feet deep. The river piers have mounds of stone round them, varying from one-and-a-half lakhs to three-fourths of a lakh; the larger quantities having been used when the river attacked the wells before their completion. In no case has the top of the stone mound sunk lower as yet than 25 feet below low water, although between some piers, where the bed is clay, the stream has scoured to 56 feet.

Span.—The beds of both spans at which this depth was attained are now floored with brick cubes for a thickness of from 5 to 10 feet. This work was an incidental consequence of the girders having been erected on stages over the deep stream.

The masonry of the wells consists throughout of hard burnt 10-inch bricks in hydraulic mortar, of a tenacity of over 200 lbs. per square inch; only whole bricks are inserted in the work throughout the cylindrical part of the wells. All broken pieces whatever were rejected, and no less than a three-fourth brick was used in corbelling.

There are twelve vertical tie-bolts of $1\frac{1}{8}$ inch round iron in each well disposed equidistantly round a circle of 18 feet diameter. The tie-bolts are connected by bottle-nuts 6 inches long at intervals averaging 16 feet 8 inches vertically, and at the same intervals there are polygonal articulated bond-rings of $3'' \times \frac{1}{2}''$ bar iron, embracing the tie-bolts. The latter pass through the curbs with a bond-ring bracing on the upper surface of the timber and heavy clamp below.

The piers have plinths 52 feet long, $15\frac{1}{2}$ feet wide, and $3\frac{1}{2}$ feet high from low water. The piers themselves are 42 feet long and 14 feet thick, and are alternately 22·6 and 23·8 high, including the bed stones.

The higher piers are the odd numbers from 1 to 17, and carry the fixed ends of the girders, while the lower piers carry the roller or expansion bed plates.

The bed stones of piers consist of six pieces, each 7 feet long, 4 feet 8 inches wide, and 2 feet high. Three stones of 4·8 feet form the width of a pier, and are tied together by iron plates $15' \times 5' \times \frac{3}{4}''$. The two tie-plates of one pier are connected on their lower side by angle irons $5' \times 5' \times \frac{3}{4}''$. These are rivetted to the plates, and have their vertical tables flat to the masonry.

The piers are finished with a corbelled and weathered cornice, open on the sides between the corbels to admit air and light to the bearings gear of the girders.

The girders are constructed according to the annexed drawings and specifications.

The temporary roadway is uniform with that of the line generally, but is laid on longitudinal sleepers, and uniformly secured by coach screws throughout in lieu of spikes. The permanent way with expansion joints is not laid, owing to the inferiority of the rails sent out from England.

The river is at present virtually confined to two spans of the bridge at its south end. In 1876 the river cut its channel laterally towards the south above bridge, so as to run for half a mile along the east side of the south approach embankment, which was prevented at the time by a copious stone protection from being undercut. During this phase of the river, a sand bank nearly as high as an average flood was raised on the up-stream side of the bridge, so as to very nearly overlap all the spans.

A breakwater is now in progress from the left bank, which has already succeeded in pushing the cold weather stream into a line square to the bridge in the three last spans. This work is faced for two miles with brick cubes of 13 inches on a side to the amount of from 200 to 500 cubic feet per foot run, according to the depth of water in front. The head, where operations for the present season and probably for all time will terminate, is protected heavily with stone. The bund will be finished 4 feet higher than any known flood, and it has a line of railway on top, from which additional protection can be launched in case of need.

Two canals, each of 150 feet in width, have been cut across the south bank, in order that flood water by surplussing through them may relieve the pressure at the breakwater head; under favorable circumstances, one or other of these canals may, by scouring its bed, draw the deep river a new and more direct channel; after much experience of the river's vagaries, the Engineers concerned are satisfied that they can certainly retain the river under the bridge.

Among minor accessories, the bridge will have the ends of the embankments at the abutments protected from scour and from slipping by heavy masses of loose stone.

The width of the bridge is somewhat more than required by the gauge of maximum moving dimensions. The lower booms form ample refuges from engines for work-people, and even trollies can be cleared by the train if put into the booms at the end bays next the piers.

TABLE OF BRIDGE TESTS.

TESTING SUTLEY BRIDGE GIRDERS, MAY 22ND AND 24TH, 1878.
Showing deflection at centre of girders, lower flange.

Spans.	TEST A.		TEST B.		TEST C.		TEST D.		TEST E.		TEST F.		TEST G.	Remarks.
	Up-stream.	Down-stream.	Up-stream.	Down-stream.	Up-stream.	Down-stream.	Up-stream.	Down-stream.	Up-stream.	Down-stream.	Up-stream.	Down-stream.		
...	Girders will be reported afterwards; it is an average.												...	
Mooltan end.														
A-B,	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$\frac{1}{2}$	...	$1\frac{3}{8}$	$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{1}{4}$	ditto.	Col. Medley.
B-C,	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{1}{4}$	ditto.	
C-D,	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{5}{16}$	not taken.			
D-E,	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{4}$	not taken.			
E-F,	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$	...	$1\frac{1}{8}$	$1\frac{1}{4}$	not taken.			
F-G,	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$	...	$1\frac{3}{8}$	$1\frac{1}{4}$	not taken.			
G-H,	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$	...	$1\frac{1}{4}$	$1\frac{5}{16}$	not taken.			
H-J,	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	...	$1\frac{1}{4}$	$1\frac{1}{4}$	not taken.			

	Amount of cambers given to the several about 4" on										Col. Medley.	Col. Bonus.
	1 1/2	1 3/4	1 1/2	1 3/4	1 1/2	1 3/4	1 1/2	1 3/4	1 1/2	1 3/4		
J-K,	...	...	...	...	...	...	...	...	...	...	Ditto.	Ditto.
K-L,	...	...	...	...	...	...	...	...	...	...		
L-M,	...	...	...	...	...	...	...	...	...	...	Others	1.8
M-N,	...	...	...	...	...	...	...	...	...	...		
N-O,	...	...	...	...	...	...	...	...	...	...	Ditto.	1.8
O-P,	...	...	...	...	...	...	...	...	...	...		
P-Q,	...	...	...	...	...	...	...	...	...	...	Ditto.	1.8
Q-R,	...	...	...	...	...	...	...	...	...	...		
Bahawalpur end.	...	...	...	...	...	...	...	...	...	...	Ditto.	1.8
	...	...	...	...	...	...	...	...	...	...		

Test A. Before load comes on, i. e., camber.
" B. Deflection on load coming on.
" C. Deflection after 10 minutes.
" D. Deflection on load coming off, i. e., set.
" E. Deflection on load passing over at 5 miles per hour.
" F. " " " 20 " "
" G. Lateral oscillation ; up-stream only taken ; mean of 4 observations.

*Note on the Indus Steam Flotilla.**Dated Lahore, 23rd December 1877.*

Annexed is a list of the steamers and flats now belonging to the Indus Flotilla, and plying between Kotri on the Indus and the Sher Shah Ghât on the Chenab.

The steamers of the first class were, I understand, built expressly for the Flotilla about 10 years ago. Differing in some details, they may generally be described as side-wheel steamers, about 220 feet in length, and 28 feet in width between the paddle boxes, with wheels $8\frac{1}{2}$ to 12 feet in diameter, driven by direct acting low pressure condensing engines. With 400 maunds of wood fuel on board and boilers full of water, they draw about four feet. They are fitted for passengers, but carry no cargo; they tow two flats, one on each side, each of which carries from 180 to 250 tons of cargo, and draws rather less water than the steamer.

With these flats, these vessels can steam down river at some 10 or 12 miles per hour; up river about four miles per hour. They do not proceed during the night. The ordinary length of a voyage from Sher Shah down to Kotri (575 miles) is from 9 to 12 days in the low season, and 5 or 6 days during the floods.

Up river the length of a voyage from Kotri to Sher Shah may be said to be 28 days in the cold season and 15 days in floods.

The average number of complete voyages (down and up) made by each vessel with her flats during the year is about 8.

The consumption of fuel is from 800 to 1,200 maunds per day on the up voyage; from 500 to 800 maunds going down.

The average cost per voyage up and down, including everything for half-year ending 30th June last, when the whole Flotilla was fully employed, was Rs. 12,270.

The average receipts per voyage for the same half-year were Rs. 18,393.

Taking the prime cost of a steamer with her flats at Rs. 4,50,000, this would show a profit of $10\frac{1}{2}$ per cent. per annum, or 33 per cent. profit on the gross receipts.

The steamers of the 2nd class were purchased by the Scinde, Punjab and Delhi Railway Company from the Government Steam Flotilla when broken up in 1869.

They are a smaller class of vessels than the others; have side wheels

driven by low pressure condensing engines; draw as much water as the larger vessels when loaded, but about one foot less when light.

They also tow flats lashed to their sides, which carry about 100 to 150 tons each.

Besides these, there are two exceptional vessels—the *Parah*, which is of light draught, and carries 150 tons of cargo, but is of too low power to steam against the floods; and the *Ravi*, lately purchased from the Bahawalpur State, which carries about 60 tons of cargo, and is a stern-wheel boat driven by high pressure engines.

There are also three steam tugs and flats or barges of sizes used as above.

The steamers of the 2nd class during the half-year ending June last averaged Rs. 7,864 as cost per voyage, and Rs. 15,113 as receipts.

Taking the cost of steamers and their flats at 3½ lakhs, this would show a profit of over 16 per cent. per annum, and 48 per cent. on the gross receipts, and would go to show that the 2nd class steamers are a good deal more profitable than the 1st class.

During the same period Rs. 1,22,000 were paid by the Company for the hire of native boats, the receipts on which were Rs. 2,12,300, being a profit of Rs. 90,300, or 42 per cent. on the gross receipts, which seems to show that it should be more profitable to the Company to hire or build native boats than to employ its 1st class steamers.

Neither of the above classes of steamers appears to me well adapted for the work in which it is employed. In a river where the deep channel is constantly shifting, and is often very narrow, it is easy to understand how unwieldy and unmanageable this combination of steamer and flats often is, forming, as it really does, one vessel 200 feet long and nearly 100 feet beam. There is often barely room to turn round, while in the upper portion of the river at least the draught, nearly four feet, is certainly too great for many of the channels in the dry season. The consequences of course are—much running aground, considerable damage to vessels and machinery, and very great delay.

All this is fully admitted by every one concerned; the question is whether it can be remedied by the obvious expedient of designing steamers which can carry their own cargo under the peculiar conditions of the problem, and although the subject has been much discussed for several years past, I cannot ascertain that the experiment has fairly been tried;

and as such steamers are common on the American rivers, several of which strongly resemble those of Upper India, I should myself be disposed to think the problem might be solved if we went the right way to work, that is, if we consulted men who had already built such steamers elsewhere, and not men of purely English experience who apparently fail to grasp the conditions of the problem.

It may be said that the question is not of much importance, as with the opening of the Indus Valley State Railway the utility of the Flotilla will, to a large extent, cease; but I am inclined to think that some of them, at any rate, may find room for employment on the upper waters of the Punjab, and that if we could get a proper class of steamers, they would very largely be employed in this manner.

What we require then are boats similar to those employed on the Missouri, Ohio and Upper Mississippi, and also, *I believe*, on the Elbe, of light draught (not drawing more than three feet six inches when laden), and driven by powerful *high* pressure engines, which will give the requisite power without the enormous weight of the engines now used, and which virtually leave no space (or at least weight) available for cargo. I published a description of such steamers two years ago in the "Roorkee Professional Papers," and I should be very glad to see them fairly tried on these rivers.

As regards the present Flotilla, of course we can only endeavour to utilize the boats to the best advantage, and I venture to suggest two or three measures, which I think would tend to increase their efficiency very greatly.

The first is, that the present pilot service should be rendered more efficient. At present there are two pilots at every station, which are about 25 miles apart. This is far too great a length for a man to keep himself thoroughly acquainted with, in rivers like these whose channels are ever shifting; and to make matters worse, the pilots have no boats to take soundings with. The consequence is, that they are often quite ignorant of the channel, as I have heard them several times declare. Ten miles of water is quite as much as a man should have in his beat; and I think three men should be kept at each station, one for the up voyage, the second for the down, and the third, with a small boat, to take soundings with daily. At present the Flotilla pays Rs. 1,000 per month for the pilot service, and I cannot help thinking that if this sum were

tripled, it would not be too much to pay for the advantages of a thoroughly efficient system of pilotage; probably, however, it would not be necessary to make the beats so short on the whole length of the river; but at least at certain bad points whose locality is well known, pilots should be stationed to conduct steamers up and down, and with a boat to take soundings. If it be said that these bad places are often changing, the reply of course is that the pilots should be shifted also. There are not more than 10 or 12 of such places, and the cost of these extra pilots would be amply repaid by the saving of delay and wear and tear of boats and machinery.

The pilots are at present under the authority of, and paid by, the Government; but as they are solely employed by the Flotilla, it would seem advisable that they should be under the direct control of the Flotilla Superintendent. I am informed that in more than one instance complaints made by Captains, of carelessness or ignorance on the part of the pilots, have met with no redress whatever.

The next proposal I should make would be that during the cold season the first class steamers and flats drawing nearly 4 feet of water should be solely employed between Sukkur and Kotri, where the navigation is attended with fewer difficulties than in the upper portion between Sukkur and Sher Shah, where the smaller steamers and flats would ply. This would, of course, involve the transshipment of a considerable quantity of the cargo, but I think the cost and delay would be more than counterbalanced by the time and risk saved.

I should also suggest that every steamer, at any rate of the first class, should be provided with a steam capstan to assist in warping her off when aground. At present this is entirely done by manual labour, which is often very severe, and yet not sufficient for the power required.

With the efficiency of the Flotilla thus increased, as I believe it would be, and with the reasons for delay *pro tanto* reduced, I believe it would be a good plan to give the crew of every vessel (from the Captain downwards) a direct inducement to shorten the length of the voyages, and so increase the number of trips per annum, by giving a bonus or otherwise, to be rateably divided, in addition to their regular pay. There may possibly be certain objections to this, but I own I do not see their force; it is simply a practical mode of giving increased pay for proficient service in a case where promotion in the ordinary manner is out of the

question, and if it be said that *luck* or *chance* would enter into the account, the same may be said of any other system.

There is a very large native boat traffic on the river, and the Flotilla actually carries but a small portion of the traffic. Until quite recently for some months past, the steamers and flats have been fully employed, and it was necessary to hire a large number of native boats to supplement the carrying capacity.

Latterly, under the influence of a bad harvest and high prices, the steamers have not been running with full cargoes, and the native boats compete successfully with them by carrying at much lower rates. Thus, while at Sukkur, I found native boats taking grain down to Kotri for $2\frac{1}{2}$ annas per maund, which, as the distance is 285 miles, is at the rate of $\frac{1}{8}$ pie per maund per mile, or about $\frac{3}{4}$ d. per ton mile. The Flotilla rate is $\frac{1}{4}$ pie or $\frac{7}{8}$ d. per ton mile for the same distance, and this rate will, it is presumed, now be lowered to attract cargo; of course the customer who employs the Flotilla has the advantage of virtually having his cargo insured, besides the saving of time, both of which advantages, however, are of less importance at this season of the year than in flood time. I mean that the saving of time is less, and the difference of risk is slighter.

One native boat lying at Sukkur had brought 800 maunds of wheat from Dera Ismail Khan, for which the freight paid was Rs. 400, or 8 annas per maund. It was now going down to Kotri with cargo from Sukkur, and would be dragged up or sail up thence laden with rails for the Indus Valley State Railway.

The very low rate at which, as above shown, it pays a native boat to carry goods, shows how formidable will be the competition of the water carriage with the railway when opened. This is, of course, only what must be expected when we consider that in the one case the road is practically ready made, and costs the carrier nothing; but it will show how necessary it will be for the Railway to adopt the lowest possible rates for goods, and to afford every possible facility to customers.

As compared with the native boat rates, the Flotilla rates are undoubtedly high, but they were raised during the pressure of traffic at the beginning of the year; the profits have been some 13 per cent. on the capital, and they will bear considerable reduction.

The great disadvantage to which the steamers will now be subjected will undoubtedly be in the up traffic, which hitherto has been chiefly the

carriage of State Railway stores, which, on the completion of the Indus Valley State Railway, will naturally cease, and as there is little else to be carried, it seems doubtful how far it will pay the steamers to run up empty, even if they get full cargoes down at the low rates to which they will be driven by the competition of the railway and native boats.

Altogether it is probable that work will be found for only a portion of the Flotilla, and the Agent agrees with me in thinking that it is desirable to ascertain without loss of time, whether some of the spare vessels cannot be employed elsewhere. With this view, enquiries will be made as to whether there are not intermediate points on the river between Sher Shah and Kotri where goods might be received, and so a local traffic could be fostered.

It appears that there are such places where grain, for instance, is received in bulk by the native boats, and efforts will now be made to secure this traffic for the Flotilla, by supplying bags and affording other facilities.

I am also in hopes that a few of the lighter steamers and flats may be employed on the upper rivers, *i. e.*, on the Indus, touching at Isa Khel, Dera Ismail Khan, and Dera Ghazi Khan: on the Sutlej up to Ferozapore; and, possibly on the Jhelum up to Pind Dádan Khan; Isa Khel is the port for the Márwat country, one of the largest grain-producing districts of the Punjab; and Dera Ismail Khan, it is well known, has a large trade. With a proper class of steamers carrying their own cargoes, I should have every hope that they would do well; whether the present steamers can thus be utilized, I am doubtful, but the attempt should certainly be made, and the Agent is well inclined to try.

He also, I may add, quite concurs in the necessity for an immediate reduction of fares, which has indeed already been carried out; as to the want of additional pilots at the bad places, which will come up for formal sanction after due enquiry; and as to the employment of the larger steamers below Sukkur only, as to which instructions have already been given as an experimental measure.

It is more than probable, however, that some of the steamers will have to be put out of commission, and that it will be expedient for the Company to get rid of some of its larger and more expensive vessels before long.

Note on the Hardwar Pilgrim Traffic in connection with the Scinde, Punjab and Delhi Railway.

Dated Lahore, 22nd April 1879.

The Hardwar Fair of the present year is the largest that has been known since 1867.

The Railway traffic in connection therewith commenced about 10th February, and lasted till the 20th April. The great bathing day was on the 11th April, and on the 13th the return traffic commenced, and continued for a week.

The number of 3rd class passengers booked over the Scinde, Punjab and Delhi Railway during the above period was 854,000; the total receipts (approximate) were Rs. 7,04,000, being an addition of 200,000 in numbers and Rs. 2,50,000 in receipts over the fair of last year.

The number of special trains run during the same time, in addition to the regular trains and passenger vehicles, often on the goods trains, was 70, running about 10,000 train miles.

Not only was every passenger carriage on the line fully employed, but 350 goods wagons, and 300 wagons borrowed from the Oudh and Rohilkhand Railway, were also utilized for carrying passengers.

The great rush was at the Saharanpur Station, the bulk of the passengers coming from the Punjab. But large numbers were also booked at Deoband and Muzaffarnagar for passengers proceeding down-country.

I visited Saharanpur twice during the height of the traffic, remaining there the whole day, so as to watch the arrangements made by the Railway authorities.

Great credit is, I consider, due to the Traffic Department of the Line for conducting so heavy a traffic with so much attention to the comfort of the travellers, and with scarcely an accident or mishap. I would especially name the Station Master, Mr. Brown, an old and valuable servant of the Company, who has now been many years at this station, and whose temper, tact and patience in dealing with the enormous crowds deserve very high praise.

To enable the tickets to be more easily procured, nine ticket windows were made available, viz., five moveable ticket boxes outside the station, two windows in the waiting shed, and two in the central booking hall. During the heavy return rush, booking went on at these almost continuously day and night.

The late abolition of the pies column for all fares over one rupee was a great help to the Booking Clerks, and I would suggest that in future this should be extended to all fares below eight annas, as large numbers were booked to Rájputra (for instance), to which the fare was 12 annas 9 pie, and the Clerks were constantly running out of change. If the fare had been 13 annas, the convenience would have been very great.

Passengers were not allowed on the platform until the special train was drawn up, when as many were gradually admitted by the Police through the central hall as could be accommodated in the train.

The rush for the carriages was of course terrific, but I saw and heard of no serious accident, and the crowd showed singular patience and good humour, which, as it comprised a large majority of stalwart men, all invariably armed with sticks (brought from Hardwar), was the more commendable.

After the rush into the carriages was over, each vehicle was visited in turn, and any over the proper number were removed.

The goods wagons employed had the upper door panels removed, two on each side, and from 30 to 35 passengers squatted in each. The ventilation was fair enough, but with iron roofs and iron sides, such wagons in the month of April are certainly not adapted to passenger traffic.

Goods wagons for this purpose should either be of wood or at least lined with wood. The whole of the side and end upper panels should be fitted with hinges to open and shut readily. There should be moveable seats to fit all round the sides, with one down the middle, which can be removed when not required for passengers. There should also be some means of readily ascending into the wagon from the *ballast*, such as a moveable ladder or steps, and there should be a bracket inside for a lamp.

Considering how often a certain number of goods wagons have to be used for passenger traffic, it seems very desirable to have from 2 to 300 wagons ready as above. I had suggested altering some of the new iron wagons, but I doubt whether this can be easily done, and the material is unsuitable for the hot weather. I would therefore ask the Agent, in amendment of my former suggestion, to consider whether some of the old wooden wagons cannot be altered at a moderate expense.

It seems very desirable in future that proper camps should be marked out by the Civil authorities at some little distance from the station where

the crowds of pilgrims can assemble and be gradually removed to the station. A train can only take about 1,200 passengers, and with a limited supply of rolling stock, a crowd of 20,000 men takes time to get away. I am informed that at one time, subsequent to my second visit, the station was completely mobbed, and arrangements almost brought to a stand still.

There is no accommodation on the station ground for such a huge crowd. If arranged in a camp with proper latrine arrangements and a good supply of water, and especially with shelter from trees, the convenience of the arrangement would be obvious, and the trees might be supplemented by thatched sheds, which might be kept in store till the next fair.

There should also be a Native Doctor on the spot with a dispensary hut or tent, and a few huts for banyahs.

The Railway authorities do what they can in these matters, but the ground is too limited for them to do very much. Considering, however, that this assemblage is an annual crowd of very profitable customers, there is no reason why the Railway should not pay the cost of these arrangements, if they had the necessary ground. Otherwise it would be better that they should be undertaken by the Civil authorities, the cost being either defrayed by the Railway or by a small fee of one or two annas levied on each pilgrim at the entrance to the camp.

It is certainly very desirable that the pilgrims should have ample means of rest and refreshment at or near the Railway Station. They arrive after a long walk of probably 20 or 30 miles, and are then crowded into badly ventilated carriages. It is therefore not to be wondered at if disease breaks out among them, and is perhaps carried all over the country. I myself saw one old man taken dead out of a carriage at Umballa, and one robust-looking man lying down at Amritsar in an exhausted state, which was said to be simply due to the heat of the carriage.

Several cases of cholera occurred in the trains during the return journey. The rule is, that when a case occurs, the carriage is cut off at the next station, the occupants turned out to go on by another train, and the carriage disinfected.

One of the papers stated that many people get into the trains who are ill. This is probable, and can hardly be prevented without a medical examination of each man before the journey, which is obviously impracticable.

cable. The Station Masters have orders to prevent any man from starting who appears ill, and notices have now been printed in the vernacular and pasted in carriages and on the platform, warning passengers who may travel when labouring under infectious disease, that they will be made over to the Police.

The Hardwar Fair, though the largest, is by no means the only fair on this line that strains the resources of the Traffic Department.

The Baisākhi festival at Amritsar, and the Pihowah Fair (near Thán-esar) both occur in the spring, and the Diwāli festival at Amritsar in November also attracts vast crowds. There are also several others of less importance.

In conclusion, I desire to suggest—

1st.—That some 200 of the old pattern wooden goods wagons should be altered as above recommended so as to carry passengers.

2nd.—That definite instructions should be issued by the North-West Provinces Government to the District authorities to demarcate certain convenient spots near to the station for future pilgrim camps.

3rd.—That the necessary cost of such camps, including temporary sheds, latrines, &c., should be paid either by the Railway or by a small tax on each pilgrim as Government may determine.

Since writing the above, I have heard that a camp was formed at Deoband by the Civil authorities. The Railway arrangements at this station are said to have been defective, and serious charges have been made against the Booking Clerks for extorting money and delaying passengers at the station, which are now under investigation.

Notes of Inspection of the Railway Works in the Beas and East Beyn Valleys.

Dated Lahore, 30th April 1879..

I visited these works and the Beas and Sutlej bridges, on the 26th instant, and the following notes show their present state:—

Beas Bridge.—The stone protection of crates and nets is now completed round all the piers, but is piled up to high flood level. Major Forbes has recorded his objections to this, and I should prefer seeing the stuff lowered, as has been done at the Sutlej bridge. It is, however, a matter which

should be left to the discretion of the Chief Engineer as the responsible officer.

Beas Embankment.—I understand that work has been commenced by the Provincial Engineers, and have asked the Superintending Engineer (Mr. Anderson) to let me know from time to time what has been done; as yet I have had no reply. There is, of course, no time to lose with regard to this work, or the *spur at Moli*, or the *alteration of the flood gaps in the Grand Trunk Road*; but if the last is to be done at the cost of the Railway, an approximate estimate of the probable cost should be sent in beforehand, and the Chief Engineer of the Railway and myself, should be told exactly what it is proposed to do.

I pass on to the bridges in the Beas Valley, sanctioned and in progress.

Fatteh Chak.—Old bridge: four 30-foot girders; uninjured, but wing-walls which were cracked, have been re-built.

The present diversion leaves the main line a little west of the Fatteh Chak, running down on to the bench on the down-stream side of the bank, which it leaves at the next bridge, the Mandora, and then makes a wide sweep to the right, rejoining the main line just beyond the Hamira bridge, the last in the valley.

The Engineers, however, have a line of their own running on from Mandora at the foot of the bank; indeed, without this, the work could not have been done.

The traffic diversion runs on the surface, and crosses the nallahs by temporary bridges, which it will be anxious work to maintain if the floods come down before the re-construction works are completed.

Mandora.—Two 60-foot girders, instead of one as before. Masonry completed, and ready for girders, which have been made up in the Engineers' Workshops in Lahore. They are ready, and have been tested. Abutments of this bridge are on wells sunk 50 feet deep; wing-walls 40 feet; pier is on a cluster of nine wells braced together and sunk 20 feet, as there were débris which prevented the same arrangement as elsewhere.

It is proposed to give a flooring to this bridge of block kunkur, but it has not yet been begun.

This is the only cluster well pier, and I certainly prefer the arrangement to one or two wells sunk to a great depth always provided that a flooring be added. It is one of those points that I should have liked to have had well discussed before work was begun, but unfortunately we

have had to act at once, with very short time for discussion, and every point is not seen at first.

The next opening is *No. 1 Flood Gap*, designed to be 2,970 feet long, the approaches down to it at both ends being 1 in 500, and the gap being spanned by rail girders on short brick piers $8\frac{1}{2}$ feet apart in the clear. The pier foundations are 4 feet below the surface ($1\frac{1}{2}$ feet concrete and $2\frac{1}{2}$ feet masonry). There is a flooring of concrete, 1 foot 3 inches thick, at surface level for the full length of the piers, and this is continued 20 feet up-stream and 30 feet down-stream by a flooring of boulders 2 feet thick.

I should certainly have preferred block kunkur to boulders, but the supply of the former is said to be limited. I should, however, like to see the junction between the concrete flooring and the boulder flooring, up and down-stream, made with block kunkur carefully packed. The present arrangement is decidedly weak, and although these flood gaps are presumed to be, to a certain extent, a temporary arrangement, it will be as well to make them as complete as time will permit.

Of this particular gap, 20 chains only ($= 1,320$ feet) are at present ordered, giving a clear waterway of 1,122 feet. As explained in my former note, I trust that none of this gap will be filled up this season. If there is not time to complete the rail girders over the whole, temporary piers should be made. Or, if nothing better can be managed, I would cut out the old earthen bank at once, and fill up what cannot be otherwise closed at the last with *new* earth or sand.

Hambowdl.—Four 60-foot girders ($= 220$ feet waterway) instead of 102 feet as before; piers will be ready for girders by 15th May. Girders are now coming up the Indus Valley Line from England.

Pier wells are 50 and 40 feet down as at Mandora; no orders for flooring as yet, and I would suggest instead that the ground should be excavated 10 feet in width and depth round the piers and along the abutments, and the excavation filled in with brick refuse or boulders, as on the Indus Valley bridges.

It is to be remarked that the whole of the surface soil in this valley is a light sandy clay, which scours into deep holes on the slightest provocation.

The question of floorings for bridges in such a soil is a very difficult one. If a really good flooring is given and continued for such a length

down-stream that all danger from the water's action has ceased, I believe deep aprons and even deep well foundations might be dispensed with. But the elements of time, quantity of material available, as well as cost, have to be taken into consideration, and until these are determined, it is difficult to make distinct recommendations on the subject.

No. 2 Gap.—Designed to be 1,089 feet long, but at present only 10 chains = 660 feet are in progress. Owing to an alteration in the position of the next bridge, I understand that 20 chains can now be added here = 1,320 feet; and I would give every foot that *can* be given.

Ramidi Nallah.—Four 60-foot girders (= 220 feet) instead of 102 feet as before. Wells here 45 feet deep; rest three feet in a stratum of clay 12 feet to 16 feet thick, and will be ready for girders (from England) by 1st June.

Wells are now ready for hearting, and I would suggest that some money might be saved by hearting them with sand, having four feet only of concrete below and above, as has been done, I believe, on the Indus Valley Line.

I would protect these piers with brick rubbish, as already recommended for the last bridge.

No. 3 Gap.—1,353 feet designed; 10 chains (= 660 feet) ordered, and no room for more owing to the two Ramidi bridges having been shifted inwards. This makes it all the more necessary that No. 2 gap should have its full length.

Ramidi.—Three 110-foot girders = 303 feet instead of 202 as before. Old bridge ran on top of girders; new bridge will run on bottom. Wells 40 and 50 feet deep in sand ready for hearting. Girders are on the spot, having been brought from the Sutlej bridge.

I would protect the piers as above recommended in lieu of a flooring.

No. 4 Flood Gap.—827 lineal feet designed; 10 chains (= 660 feet) ordered, but not yet begun; five chains more can be added owing to the shifting of the Ramidi bridge, and I hope this will now be given. It will *all* be wanted here.

West Beyn.—Four 110-foot girders = 404 feet; pier wells are 31 feet down, of which 20 feet are in sand, and the lower 11 feet in a bed of clay, said to be of considerable thickness. If so, further sinking should be stopped. Girders are coming from Sutlej; those for two spans are already on the spot.

I would protect these piers as at the other bridges.

No. 5 Flood Gap.—992 feet designed; 17 chains (= 1,122 feet) ordered, but not begun. The sooner these gaps are cut out to their full length and depth, the better. The large bridges are *not safe* without them, and the two gaps on both sides of the West Beyn are specially important, as we know there is a great deficiency of waterway (apart from the river-spill) at this part of the valley.

Chattar Singh and Hamira.—Both thrown into one; four 60 feet girders and two 54 feet girders. Wells will be ready for hearting by 20th May.

The old Hamira bridge has been closed up, as explained by Chief Engineer, in former note, and the Provincial Superintending Engineer has promised to close up the corresponding gap in the road, but it has not yet been done.

The waterway of the whole valley, as shown in my former (2nd) note, was designed to be 1,882 lineal feet instead of 1,020 as before, *besides* 6,831 (= 5,797 in the clear) of flood gap. One would therefore suppose that an over liberal provision had been made. I can only say that I do not think there will be too much, and that any one who saw the signs of the last floods, even two months afterwards as I did, would not be inclined to under-estimate the waterway required for a similar one. It will be after all, when fully completed, less than one-fourth of the entire width of the valley, and should the Beas take a determined set in this direction, in spite of our embankments and spurs, we shall have to bridge the remaining three-fourths.

The question is so difficult a one that I own I would gladly have been able to suspend action for a year, so as to consider the subject in all its bearings and to collect the best engineering advice procurable. Unfortunately, as already remarked, we have had to act at once according to the best light available; and if mistakes have been made in working out the problem, I hope the difficulties will be considered.

Meanwhile, I must not omit to do justice to the great energy with which the works have been pushed on, especially in an unusually sickly season, though fortunately one of exceptional freedom from rain.

East Beyn Works.

The bridge over the East Beyn will consist (as stated in my former

note) of 2 spans of 136 feet and 2 of 110 feet. The girders for the former are on their way from England, and are, I think, landed; the latter girders will come from the Sutlej, or rather are already on the ground.

The pier wells are 45 feet deep, and are in 17 feet of clay; why it was thought necessary to take them down so deeply into the clay I do not know.

The large openings are flanked on each side by three 30 feet girders on masonry piers which go down 30 feet, and rest in two or three feet of clay.

On the east side, the last of these piers becomes the abutment of the new bridge. On the west side, there is a viaduct of 36 16-foot girder flood openings connecting the bridge with a 40-foot girder bridge which stood through the floods.

The piers of this long viaduct are eight feet below surface level, but at present there is no flooring. I am not sure that it is needed, for the surface soil is of clay, and the bank was literally wiped off the ground by the flood without any scour, but it should be added when there is time.

I am sorry now that more flood openings were not provided at the east end also, instead of enlarging the main channel by the additional 30 feet girders, as it appears to me in such a stream as this, where the floods come down with exceptional violence, but are of short duration, that we want *length* of waterway rather than *depth*. I conclude orders will be given to cut away the earthen shoulder so as to get the full benefit of the increased waterway in the main channel.

I have already spoken of the dangerous character of the deep S curve taken by the stream above the bridge which threatens to cut its way up to the new viaduct in two or three more floods, and which undoubtedly tends to spill the water over the surface, by heaping it up at the bends, instead of carrying it down the channel; and after my last visit, I would suggest to the Chief Engineer to consider the propriety of cutting through the neck between the two last bends, and throwing a bund across the main channel so as to keep the stream further from the railway bank and send it down straighter on to the bridge.

I do not understand why the rail level is to be raised so much on the east side of this bridge, and shall be glad of explanation. With the very large additional waterway now given, the flood line cannot be expected to reach the same height again that it did last year, and it would,

as already remarked, be better to spend the money in additional flood openings on the east side than in raising the bank and piers. I should be glad for this point to be re-considered if not too late.

Sutlej Bridge.

The 18 girders in the nine spans nearest the Ludhiana end, which were authorized to be removed, have been removed without interruption to the traffic, 14 having gone to the Beas Valley bridges and 4 to the East Beyn.

The stone groyne is being continued down to the new abutment, the water slope being covered by lines of nets filled with stones, and it is hoped the reclaimed land between the railway bank and the groyne will be still further silted up this season. No time should be lost in sowing or planting the whole of this space with sissu trees, as has been done at the Ravi with excellent effect. The Forest Department might be asked to help in this.

The tree spurs, which the Chief Engineer proposed to start on the left bank below Kariánah, as recommended by Major Forbes, have not yet been begun. I trust this work will not be lost sight of, late as it is in the season. The action of the river on the left bank below Kariánah is, as pointed out by Major Forbes, decidedly dangerous, and it will only be by works continued through successive years that the danger of a breach in the railway bank towards Ludhiana can be guarded against.

In all other respects the river looks well. The protection of the piers by crates and nets has been nearly completed; and when this is done, it will remain gradually to fill up the deep holes between the piers to within a certain distance below low-water level, so as to secure a tolerably uniform section.

The steam dredger is doing a certain amount of work in removing a sand bank from the centre of the channel, but I fear she is not doing the work that was expected of her, and I have called for a special report, as, if she is a failure, it will be better to stop further unprofitable expenditure and endeavour to utilize her elsewhere, or in some other capacity.

J. G. M.

P.S.—The above works in the Beas and Beyn Valleys have since been completed at a cost of 18 lakhs, and the former severely tried by a high flood on the 12th August, which, however, did no damage.

No. CCCXXI.

NOTE ON EXPERIMENTS MADE TO DETERMINE THE TRUE CO-EFFICIENT OF THE DISCHARGE OF THE HEAD SLUICE OF THE MIDNAPORE CANAL.

[*Vide* Plates I. and II.]

By J. W. APJOHN, Esq., *Executive Engineer, Cossye Division.*

MOST Canal Engineers must have had cause to distrust the formula $v = 5 \sqrt{H}$ generally in use for determining the velocity through a sluice due to the difference between the levels of the water surfaces on either side of it. It seems to be usual* to assume that all sluices have the same *vena contracta*, whether they are small sluices discharging free into the air under a large head of water, or have very large openings completely submerged with a difference of water level on either side of only a fraction of a foot. Hitherto, at least in Bengal, it has been the practice to use the above formula, the co-efficient of which is due to a co-efficient of contraction of .625, even for the head sluices of canals where the head is very small and the area of the submerged vents large, although the above co-efficient was determined from experiments made with very small valves in lock gates subjected to large heads.

2. In order to, if possible, determine the true co-efficient for the head sluice of the Midnapore Canal, a series of most careful experiments were carried out during last irrigating season. The field work was done by Mr. A. Hayes, Assistant Engineer, put on special duty for the purpose, under the supervision of, and frequently assisted by, the writer.

3. For the purpose of arriving at the true formula, two entirely different systems were adopted, *viz.*, firstly, gauging the discharge of the canal, and secondly, current meter observation in the head sluice itself. The discharge of the canal was carefully gauged on twelve occasions, about

* Author writes for Bengal I hope without warranty. Assuredly these remarks do not apply to N.-W. Provinces or Panjab. Capt. Cunningham's Note at end was forwarded with article by Secretary to Government, Bengal Irrigation.—[ED.]

three-quarter of a mile from the head, the relative levels of the river and canal being simultaneously observed, and the lift of the head sluice shutters; the above three elements being determined, it is evident that there are data for calculating the value of x in the formula $v = x \sqrt{H}$.

4. The gauging of the discharge of the canal was conducted with the greatest care; a portion of the canal free from eddies being found, two careful cross sections, 50 feet apart, were made, and the distance between the foot of the slopes on either side being divided into six parts, the velocity at each point of division was obtained by timing a rod float reaching to within a few inches of the bottom for the run between the ropes stretched across the site of each cross section. At each point a minimum number of three float observations were made, and in every case observations were continued, until at least three in close agreement were obtained. The velocity was observed in nine vertical planes, *viz.*, over the middle of each slope, over the toe of the same, and at each of the remaining five points dividing the bed into six portions. The discharge of the centre portion was then calculated by Weddle's formula—

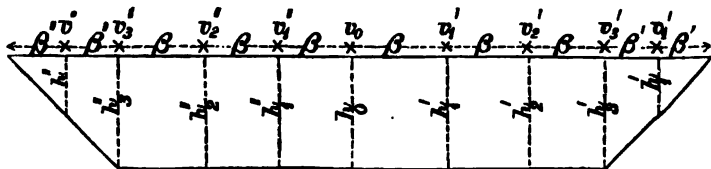
$$D = \frac{3}{10} \beta \{ h_3'' v_3'' + h_1'' v_1'' + h_0 v_0 + h_1' v_1' + h_2' v_2' \\ + 5 (h_2'' v_2'' + h_0 v_0 + h_2' v_2') \}$$

and that of the portions over the slopes by Simson's formula—

$$D_1 = \frac{1}{3} \beta' (h_2' v_2' + 4 h' v')$$

$$D_2 = \frac{1}{3} \beta'' (h_2'' v_2'' + 4 h'' v'')$$

the symbols used in the formulas refer to the following diagram—



It need only be said further that the system adopted in gauging the discharge of the canal was in every respect that employed at Roorkee by Captain Allan Cunningham, R.E.

5. A plan of the head sluice is given in *Plate I.*, and the position of the gauges is shown on the plan by the letters A and B, A being the river gauge, and B the canal gauge, the former being close to the river face of the sluice, and the latter 150 feet from the canal face.

6. The Cossye river being subject to very sudden changes of level dur-

NOTE ON EXPERIMENTS TO DETERMINE TRUE CO-EFFICIENT, ETC. 3

ing the irrigation season, it was often useless to take observations on account of the variations in the levels during the process of gauging, (which occupied from three to four hours,) and in consequence only 12 good observations were obtained, the details of which are given in the following Table. In the majority of these observations the levels did not appreciably vary during the gauging, the maximum difference between the gauges at the beginning and end of the operation being that on the 14th September, when the river gauge varied during the time by 0.3 feet, and the canal gauge 0.2 feet.

TABLE No. 1.

Date of observation.	GAUGE READINGS.				HEAD ON SLUICE.			SQUARE ROOTS OF HEADS.		Observed discharge.	HEAD SLUICE.		VALUES OF x IN FORMULA $v = x \sqrt{H}$	
	River.		Canal.		Observed.	Correction to be added.		Observed head.	Corrected head.		Area of ventage open.	Velocity through vents due to observed discharge.	Due to observed head.	Due to corrected head.
	Before experiments.	After experiments.	Before experiments.	After experiments.		Correction to be added.								
1	2	3	4	5	6	7	8	9.	10	11	12	13	14	15
Sep. 14,	81.96	81.66	81.66	81.46	.25	.07	.32	.50	.56	891	175	5.09	10.2	9.0
" 17,	82.26	82.26	81.94	81.91	.36	.08	.44	.60	.67	968	175	5.50	9.1	8.8
" 21,	80.98	80.98	80.85	80.85	.13	.05	.18	.36	.42	745	175	4.25	11.8	10.1
" 23,	82.15	82.25	81.81	81.88	.35	.08	.43	.60	.66	1016	175	5.80	9.4	8.8
" 26,	82.20	82.15	81.87	81.85	.32	.08	.40	.56	.63	1010	175	5.80	10.3	9.2
" 27,	82.02	81.95	81.70	81.70	.28	.07	.35	.53	.60	900	175	5.14	9.7	8.6
Oct. 10,	81.30	81.27	81.15	81.12	.15	.05	.20	.40	.44	722	175	4.12	10.3	9.4
" 12,	81.00	81.00	80.90	80.90	.10	.05	.15	.31	.40	686	175	3.09	9.9	7.7
" 15,	81.14	81.14	80.79	80.79	.35	.05	.40	.60	.63	600	125	4.80	8.0	7.6
" 16,	81.17	81.18	80.82	80.82	.35	.05	.40	.60	.63	675	125	5.40	9.0	8.5
" 17,	81.25	81.30	80.98	81.14	.28	.04	.30	.50	.54	502	125	4.00	8.0	7.4
" 22,	81.58	81.58	81.29	81.28	.30	.04	.34	.54	.58	548	125	4.88	8.1	7.4
Averages,	..	..	..	..	..	..	.31	..	.58	..	..	4.78	9.48	8.5

4 NOTE ON EXPERIMENTS TO DETERMINE TRUE CO-EFFICIENT, ETC.

7. In the above Table the mean of the difference between the river and canal at the beginning and end of the gauging is taken as the head on the sluice, and is entered in column 6, and its square root is then divided into the velocity, found by dividing the area of the sluice ventage into the observed discharge, and the quotient is the value of the co-efficient in the formula $v = x \sqrt{H}$; the several values obtained for x being shown in column 14. Inspection of column 14 shows the remarkable result that the co-efficients obtained vary from 8 to 11.8, and average 9.48, whereas 8 is the maximum co-efficient due to the force of gravity unreduced by *vena contracta*. As a co-efficient greater than that due to gravity is impossible, the above results cannot be correct, and they point to the real head having been greater than that given by the difference of readings of the two gauges. The relative levels of the gauges were most carefully checked by both Mr. Hayes and the writer, and they were finally adjusted absolutely level with each other, so there was no error in the gauges to account for the results obtained. But a phenomenon observed on the 23rd and 26th September goes far to explain the high co-efficient. On these occasions the writer, by very careful observation, found that the level of the canal water was 0.05 greater on the gauge 150 feet distant from the sluice, than it was close by the newel marked D on the plan; and again the level at the point C in the still water close to the river groyne opposite the sluice at a distance of about 150 feet was greater than that shown on the gauge at A by .03. If, therefore, the difference of level between the water surfaces at C and D be taken as the head, it will diminish the co-efficient observed on the 23rd September from 9.4 to 8.8, and that of the 26th from 10.3 to 9.2.

8. The fact of the surface at B being higher than that at D, is only what might be expected, as a back eddy is always observed inshore towards the sluice, and this eddy is evidently due to the reaction from the piling up of the water at B. Attempts to determine the difference of level between the water at A and C and B and D on subsequent occasions were not successful in consequence of wind disturbance chiefly, but it is a fair assumption that the total difference would be in proportion to the observed discharge of the canal, and on this principle the observed head has been increased by the fraction shown in column 7, which is obtained by multiplying .08 by the observed discharge, and dividing by 1,000 the discharge observed on the days that the difference .08 was detected. By

thus correcting the observed heads, the mean of the co-efficients is reduced to 8.5, or to little more than that due to gravity.

9. There is no reason why the surface near the newel should be the lowest, and it is quite possible that the minimum level is somewhere else, and that if it could only be determined, the exact theoretical co-efficient would be found to be correct. A further explanation of the excess of the observed co-efficient over the maximum theoretical is that the velocity through the sluice is increased by the velocity of approach to the sluice of the water in the river channel. On every occasion but the 14th September the under-sluices were closed, and the velocity in the channel above the sluice was moderate, varying from 1.5 to 2.0 feet per second; but if the mean corrected head, which is .31, be increased by .05, (the head due to a velocity of 1.8 feet per second,) the mean co-efficient is reduced to exactly 8.

10. It may be said that it is impossible that the *vena contracta* should be entirely eliminated, but it does not seem so to the writer, as the cutwaters of the sluice act as powerful adjutages, and with the piers of the sluice form an outlet of almost the most favorable form possible for the discharge of water. In most of the experiments the lower edges of the shutters were barely immersed in the water. These experiments serve to the writer to show that to determine the discharge of a canal, the formula $v = 8 \sqrt{H}$ will give very approximate results, certainly much nearer the truth than $5 \sqrt{H}$ now generally used.

11. The second method adopted was that of directly determining by observation with the current meter the mean velocity through the sluice. For this purpose a platform was formed by a board between the piers of the middle vent of the sluice, at a height of about two feet above the level of the water flowing between the piers, and standing on this platform the observer worked the current meter fixed to the end of a light pole; the current meter used was of the usual kind, with a fan 4 inches in diameter. Before the experiments were begun, it was tested in still water and found correct. It was found that with a little practice that it was quite easy to observe the velocity at different points in the cross section. The operator stood up on the platform facing the current, and resting the pole of the current meter in a notch in the edge of the platform (which determined the distance of the observation from the centre), he slid down the pole until the current meter was the required depth below the surface; the current meter was then thrown into gear by

pulling a wire led up the pole through rings like those on a fishing rod. In each experiment the current meter was run for 30 seconds, the time being called by an assistant, chronograph in hand. The observations were repeated at each point, until three closely approximating readings were obtained.

12. At first it was supposed that the mean velocity might be determined from a few observations at different depths in the middle between the piers, and a few more on one side to show the diminution of velocity close to the wall. However, after a considerable number of observations had been made, it was discovered that the velocity on either side of the centre were not symmetrical, but that those to the east were invariably greater than those to the west of the centre; the writer therefore on the 4th November made a very careful series of observations at altogether 24 different points in the cross section, the readings of the current meter being 82 in number. The diagram, *Plate II.*, represents a cross section of the space between the piers, and it shows on it all the particulars of the observations made. The intersections of the vertical and horizontal lines mark the points where the readings were taken, and the actual readings are shown in small figures above and below the point where they were taken. The average of each group is shown under it in heavy black figures, and at places where no readings were taken, the interpolated velocities are given in heavy figures marked with an asterisk. It was not possible in any case to observe closer to the pier than three inches without fouling the face of the current meter, and even so close could only be done just beneath the surface, but at intervals down to 5 feet readings were taken in five different planes, but below 5 feet only in the centre, as at such a depth it would have been difficult to lower and raise the current meter without striking the wall if an attempt had been made to work it close to the side. Having given the above description of the method adopted to observe the velocities, the details of the calculations of the mean velocity from those observed will be proceeded with.

13. The velocity was observed in seven different places parallel to the axis at a depth of a few inches from the surface, (just sufficient to immerse the fan of the current meter.) These planes were that through the centre, and those at a distance from either side of 3 inches, 6 inches, and one foot. At the depths of 1, 3 and 5 feet from the surface, the velocity was determined in five planes, *viz.*, the centre plane and those at

a distance of 6 inches and one foot from either side. At the depth of 6 feet 6 inches only the centre velocity was observed, as was likewise done within a few inches of the bottom, or at a depth of 7 feet 4 inches. Reference to the diagram shows the number of separate observations made and their positions in the vent, (the decimal point of the middle velocity in each group is on the intersection of the vertical and horizontal lines which indicate the point in the vent at which the observations were made.)

14. The probable velocity close to the walls at the depths of 1, 3 and 5 feet have been calculated by assuming the relation observed near the surface between those velocities and those in the adjacent planes to be generally true, viz., that if v_1 be the velocity at 3 inches from the wall, v_2 that at 6 inches, and v_3 that at 12 inches, $v_1 : v_2 : v_3$. At the surface this proportion is very nearly true on both sides of the vent. For the depths of $6\frac{1}{2}$ and $7\frac{1}{2}$ feet, where only the centre velocities were observed, the velocities close to the side are calculated by assuming them to bear the same ratio to the centre velocities, as they were found to do on an average at the four lesser depths, viz., .65 on the west side and .73 on the east. The principle on which the interpolations have been made being now explained, the calculation of the mean velocity will be proceeded with.

15. At surface—

$$\left. \begin{array}{l} 1.91 \times .5 = 0.95 \\ \frac{2.15 + 2.37}{2} \times .5 = 1.18 \\ \frac{2.37 + 3.22}{2} \times 1.5 = 4.19 \\ \frac{3.22 + 3.40}{2} \times 1.5 = 4.97 \\ \frac{3.40 + 3.03}{2} \times .5 = 3.21 \\ 2.83 \times .5 = 1.42 \end{array} \right\} \div 5$$

v at surface = 3.17 feet per second.

At 1.0 feet below surface—

$$\left. \begin{array}{l} 1.75 \times .5 = 0.87 \\ \frac{1.91 + 2.08}{2} \times .5 = 1.00 \\ \frac{2.08 + 3.45}{2} \times 1.5 = 4.14 \\ \frac{3.45 + 2.77}{2} \times 1.5 = 4.67 \\ \frac{2.77 + 2.42}{2} \times .5 = 1.30 \\ 2.17 \times .5 = 1.08 \end{array} \right\} \div 5$$

v at 1.0 below surface = 2.61 feet per second.

8 NOTE ON EXPERIMENTS TO DETERMINE TRUE CO-EFFICIENT, ETC.

At 3.0 feet below surface—

$$\left. \begin{array}{l} 2.66 \times .5 = 1.33 \\ \frac{3.63 + 4.09}{2} \times .5 = 1.98 \\ \frac{4.09 + 4.34}{2} \times 1.5 = 6.32 \\ \frac{4.34 + 4.50}{2} \times 1.5 = 6.63 \\ \frac{4.50 + 3.63}{2} \times .5 = 2.03 \\ 2.42 \times .5 = 1.21 \end{array} \right\} \div 5$$

v at 3 feet below surface = 3.89 feet per second.

5.0 feet below the surface—

$$\left. \begin{array}{l} 3.2 \times .5 = 1.60 \\ \frac{3.36 + 3.52}{2} \times .5 = 1.72 \\ \frac{3.52 + 4.46}{2} \times 1.5 = 5.99 \\ \frac{4.46 + 4.63}{2} \times 1.5 = 6.81 \\ \frac{4.63 + 4.04}{2} \times .5 = 2.17 \\ 3.52 \times .5 = 1.76 \end{array} \right\} \div 5$$

v at 5.0 below surface = 4.01 feet per second.

6.5 feet below surface—

$$\left. \begin{array}{l} \frac{2.67 + 4.12}{2} \times 2.5 = 8.49 \\ \frac{4.12 + 3.00}{2} \times 2.5 = 8.90 \end{array} \right\} \div 5$$

v at 6.5 below surface = 3.48 feet per second.

At bottom 7.86 below surface—

$$\left. \begin{array}{l} \frac{1.76 + 2.71}{2} \times 2.5 = 5.59 \\ \frac{2.71 + 1.97}{2} \times 2.5 = 5.85 \end{array} \right\} \div 5$$

v at bottom = 2.49 feet per second.

Mean velocity for the whole depth will be determined from the mean velocities at the observed depths as follows:—

$$\left. \begin{array}{l} \frac{3.17 + 2.61}{2} \times 1.0 = 2.89 \\ \frac{2.61 + 3.89}{2} \times 2.0 = 6.50 \\ \frac{3.89 + 4.01}{2} \times 2.0 = 7.90 \\ \frac{4.01 + 3.48}{2} \times 1.5 = 5.61 \\ \frac{3.48 + 2.49}{2} \times .86 = 2.56 \end{array} \right\} \div 7.36$$

v for whole depth = 3.46 feet per second; but the depth for which 3.11 is the mean velocity is greater than the height of the vent, as the total lift of the shutter was 7.00, therefore the mean velocity through the vent will be

$$3.46 \times \frac{7.36}{7} = 3.63 \text{ feet per second.}$$

16. The mean velocity in the centre plane may be calculated as follows:—

$$\left. \begin{array}{l} \frac{3.22 + 3.45}{2} \times 1 = 3.33 \\ \frac{3.45 + 4.34}{2} \times 2 = 7.79 \\ \frac{4.34 + 4.46}{2} \times 2 = 8.80 \\ \frac{4.46 + 4.12}{2} \times 1.5 = 6.43 \\ \frac{4.12 + 2.71}{2} \times .86 = 2.94 \end{array} \right\} \div 7.36$$

v in central plane = 3.98 feet per second; but the mean velocity for the whole section = 3.46 feet per second—

$$\frac{3.46}{3.98} = .87.$$

It therefore appears that the mean velocity through the head sluice is the mean velocity in central vertical plane multiplied by .87.

17. Assuming the relation just established between the mean velocity for the whole vent and that for the central vertical to be general, observation made on five previous occasions can be utilized, as in all cases the velocities were determined at several depths in the central plane. The details of the calculations have, for the sake of brevity, been put into the following tabular form, the headings of which explain themselves. In the 3rd column the velocities, which have been interpolated, are marked with an asterisk, but it will be observed that the only ones interpolated in any case are the surface and bottom velocities, and that velocities were in every case observed at from five to six intermediate depths.

TABLE No. 2.

Date of experiment.	Depth from surface of each group of observations.	Mean of each group of observations.	Mean velocity for each stratum.	Thickness of stratum.	Product of velocity and thickness of stratum.	Mean central velocity between piers, being previous column divided by depth.	Mean velocity between piers, being central velocity $\times .87$.	Depth between piers divided by lift of shutter.	Mean velocity for vent open, product of previous two columns.
1	2	3	4	5	6	7	8	9	10
September 2nd.	Surface (0)	*2.35							
	1.0	2.61							
	2.0	3.00							
	3.0	3.03	2.76	5	13.80				
	4.0	2.93				2.63	2.28	$\frac{6.34}{6.34}$	2.28
	5.0	2.65							
	bottom (6.34)	*1.70	} 2.17	1.34	2.90				
September 7th.	Surface (0)	*4.15							
	1.0	4.61							
	2.0	4.28							
	3.0	4.73	4.46	5	22.30				
	4.0	4.61				4.19	3.64	$\frac{7.36}{7.00}$	3.82
	5.0	4.37							
	bottom (7.36)	*2.91	} 3.64	2.36	8.59				
September 9th.	Surface (0)	*3.14							
	1.0	3.49							
	2.0	3.90							
	3.0	3.85	3.65	6.0	21.90				
	4.0	3.87						$\frac{6.6}{6.6}$	3.17
	5.0	3.50				3.64	3.17		
	6.0	3.78							
	bottom (6.6)	*3.28	} 3.53	0.6	2.12				
September 14th.	Surface (0)	*3.24							
	1.0	3.60							
	2.0	4.66							
	3.0	5.40	4.36	6.0	26.16	4.32	3.76	$\frac{7.5}{7}$	4.02
	4.0	5.29							
	5.0	5.32							
	6.0	5.00							
	bottom (7.5)	*3.30	} 4.15	1.5	6.22				
September 17th.	Surface (0)	*3.80							
	2.0	4.47							
	3.0	6.35	4.13	2.0	8.26				
	4.0	6.74	6.17	4.0	24.68	5.40	4.69	$\frac{8.0}{7.0}$	5.36
	5.0	6.86							
	6.0	6.45							
	bottom (8.0)	*3.87	} 5.16	2.0	10.32				
Sept. 21st.	Surface (0)	3.68							
	1.0	4.09	3.88	1.0	3.88			$\frac{7.0}{7.0}$	3.79
	3.0	4.75				4.35	3.79		
	5.0	4.86	4.26	6.0	25.56				
	bottom (7.0)	3.33							

NOTE ON EXPERIMENTS TO DETERMINE TRUE CO-EFFICIENT, ETC. 11

18. The results of the five observations, the details of which are given in Table No. 2, are shown in the following Table No. 3, and also the mean velocity determined by the elaborate experiments of November 4th. In this Table the observed heads have been corrected in the same way as in Table No. 1, by adding to them $\frac{.08 \times \text{calculated discharge}}{1000}$, and the co-efficients so obtained vary from 7.6 to 9.5, and average 8.4, thus only differing by 0.1 from the mean co-efficient 8.5 determined by the gauging of the canal discharge.

TABLE No. 3.

Date of observation.	GAUGE READINGS.				MEAN HEAD ON SLUICE.			SQUARE ROOTS OF HEADS.		Mean velocity observed by current meter.	Discharge of canal due to velocity through sluice.	VALUES OF x IN FORMULA $v = x \sqrt{H}$	
	River.		Canal.		Observed.	Correction to be added.	Corrected head.	Observed head.	Corrected head.			Due to observed head.	Due to corrected head.
	At beginning.	At end.	At beginning.	At end.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sep. 7, ..	81.21	81.06	81.11	80.96	.10	.05	.15	.31	.40	3.82	670	12.3	9.5
" 9, ..	80.61	80.58	80.51	80.46	.11	.04	.15	.33	.40	3.17	518	9.6	7.9
" 14, ..	81.66	81.56	81.46	81.38	.19	.06	.25	.45	.50	4.02	7.0	9.0	8.0
" 17, ..	82.26	82.4	81.91	81.88	.34	.07	.41	.58	.64	5.36	938	9.2	8.4
" 21, ..	80.98	80.98	80.85	80.85	.13	.05	.18	.36	.42	3.79	663	10.5	9.0
Nov. 4, ..	81.42	81.40	81.24	81.22	.18	.05	.23	.42	.48	3.63	635	8.6	7.6
Averages,	..	..	..	..	..	..	..	..	..	..	..	9.9	8.4

19. The writer thinks that it will be admitted that the above experiments if they do not absolutely establish the true co-efficient, go far to show that there is no appreciable *vena contracta* in large sluices with small heads, and that the best formula to use to determine the velocity is $v = 8 \sqrt{H}$. In this note the observations made are given in sufficient detail to allow of any one who wishes working them out and possibly arriving at a different conclusion from that given above. A recent writer on Hydraulics, Jackson, says that the question of true formula for the discharge through a sluice is one that has little interest for Canal Engi-

neers; but in this he seems to be mistaken, as until such a formula has been discovered, it is impossible to tell what the actual daily discharge of a canal may be, and consequently the duty obtained from the water remains undetermined. The writer regrets that in consequence of his being about to leave India on furlough, he will be unable to further pursue the question experimentally for sometime to come, but he hopes that some other Canal Engineers may be induced to take the question up, so that eventually some definite conclusion may be arrived at.

J. W. A.

Note on Mr. Apjohn's Experiments. By CAPT. ALLAN CUNNINGHAM, R.E.

See paras. 4 and 11.—1°. The principle of selecting out of many velocity-measurements only those which are nearly equal, is contrary to all principles of scientific discussion. If they were all done with equal care, they are all equally trustworthy and should be all used.

See para. 9.—2°. The mode of using the formula $v = x \sqrt{H}$ appears incorrect. The symbol H should include the height due to velocity of approach.

With the very small heads of these experiments (from .10 to .36 of a foot), this term, *i.e.*, the height due to velocity of approach, is a very important one: its omission is one considerable cause of the unusually large co-efficients obtained, and causes an increase in the co-efficient increasing rapidly with decrease of a small head.

[The effect is clearly shown in both Tables I. and III., the large co-efficients corresponding generally to the small heads].

The omission cannot well be supplied now: the "velocity of approach" should be the velocity at the cross section at which the water level for the upper head is taken.

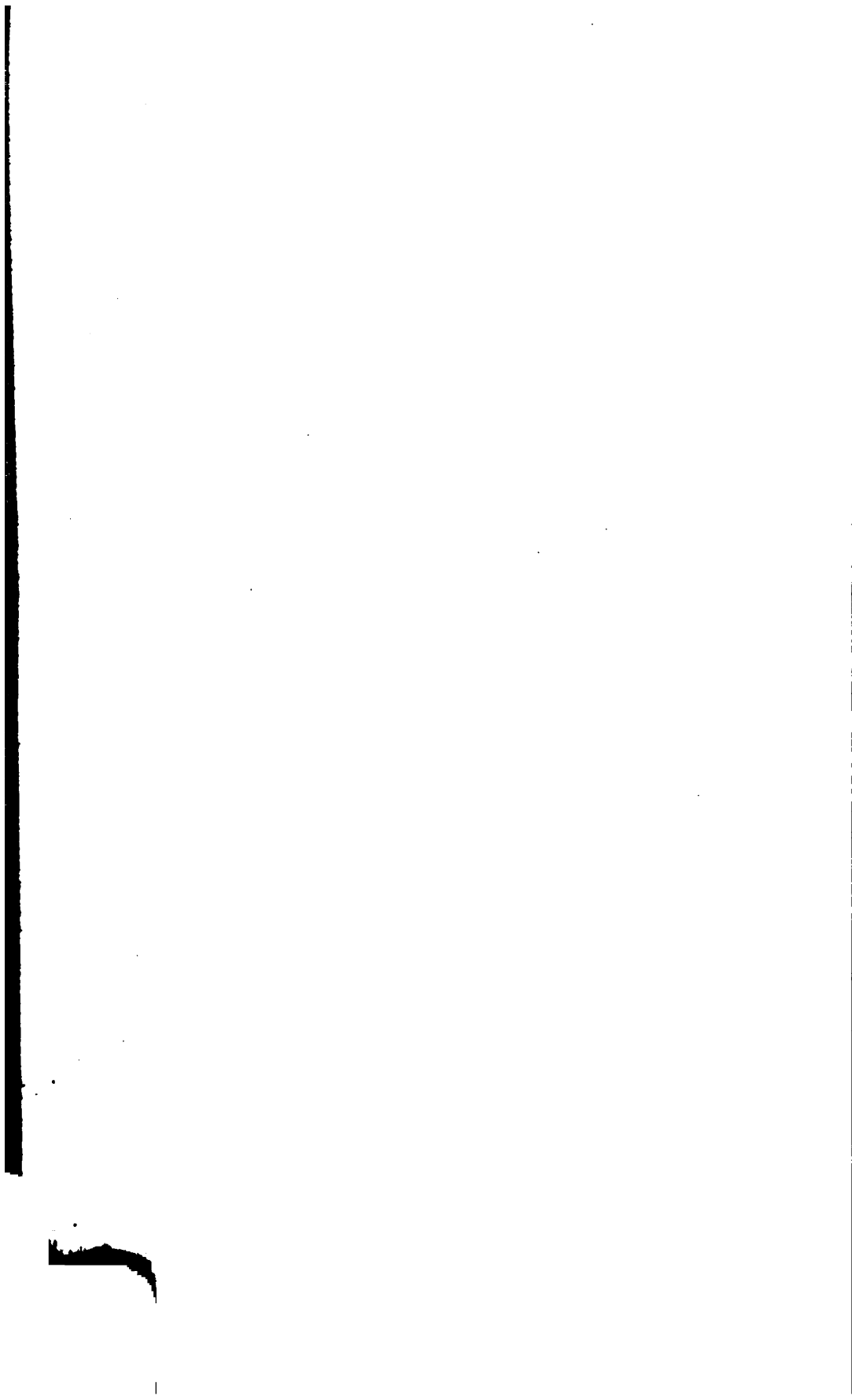
See para. 7.—3°. The "heads" of water are so small that their accurate determination is difficult. The two gauges marked C and B in Plate I., would have given probably the better values for use in the formula $v = x \sqrt{H}$; but the uncertainty of applying a conjectural correction of .08 to heads of only .10 is of course enormous.

See para. 11.—4°. In the experiments with current meters, it should have been stated whether the meter had been tested in still water throughout the whole range of velocities (about 4.5 to 1.5 per second) for which

NOTE ON EXPERIMENTS TO DETERMINE TRUE CO-EFFICIENT, ETC. 13

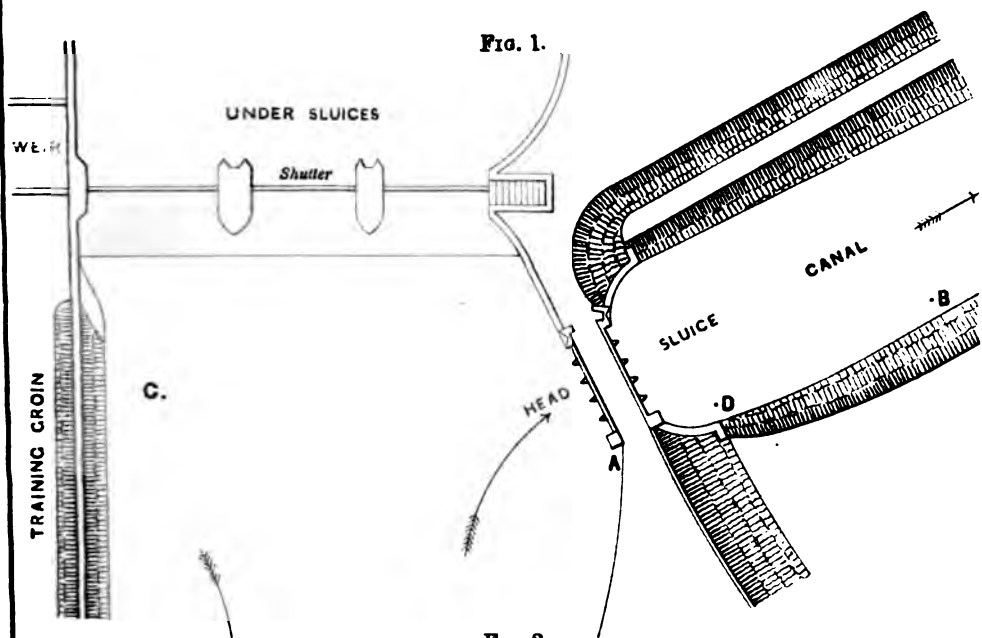
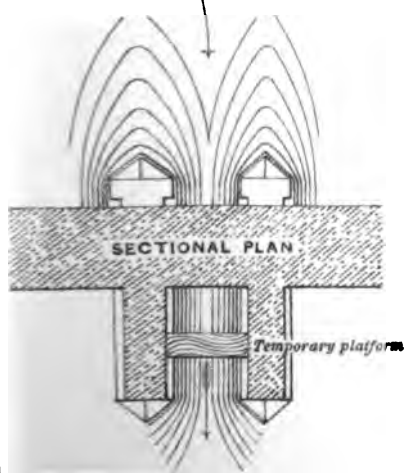
it was used : as most meters require a different co-efficient to be applied to the indicated revolutions at different velocities.

5°. The expectation of foretelling the supply entering the canal from a mere inspection of the gauges and use of some formula such as $v = x \sqrt{H}$, is probably futile, so long as the important term "velocity of approach " is unknown, (*v. supra*).

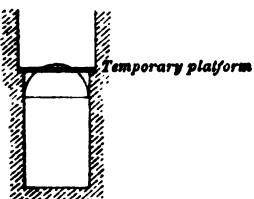
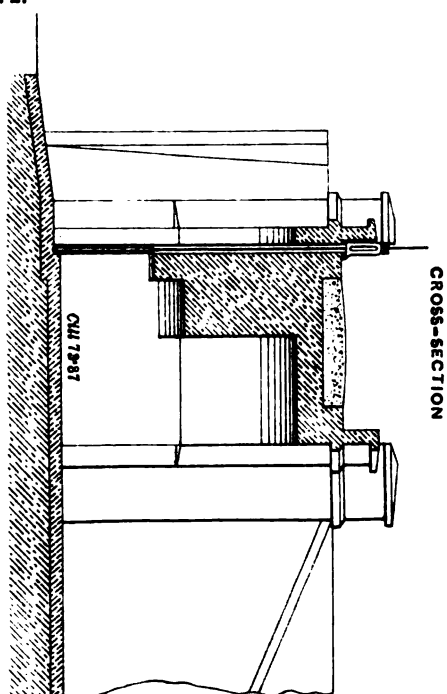


NOTE ON EXPERIMENTS MADE TO DETERMINE THE TRUE CO-EFFICIENT OF THE DISCHARGE OF THE HEAD SLUICE OF THE MIDNAPORE CANAL.

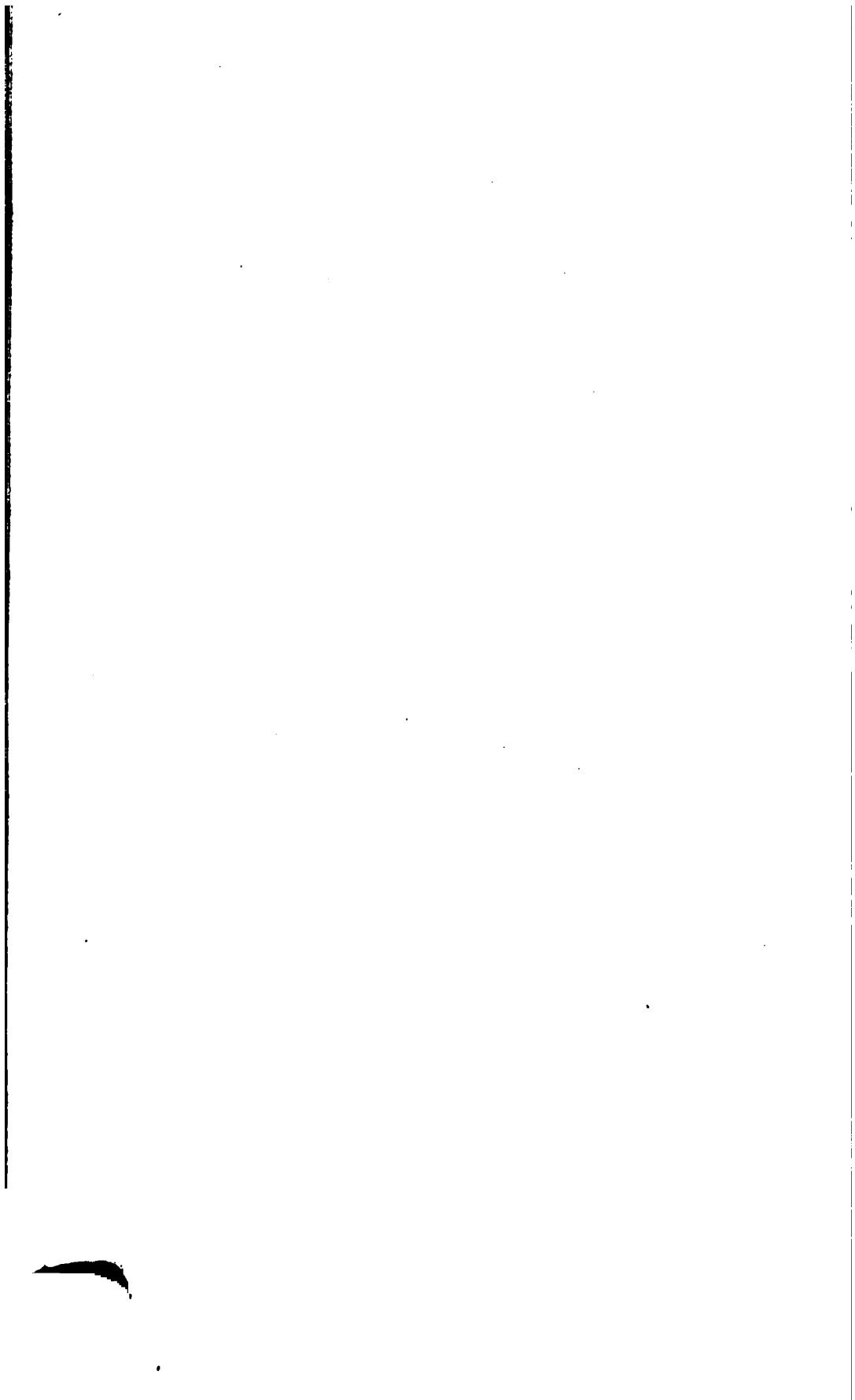
Scale, 90 feet to 1 inch.



SECTIONAL ELEVATION

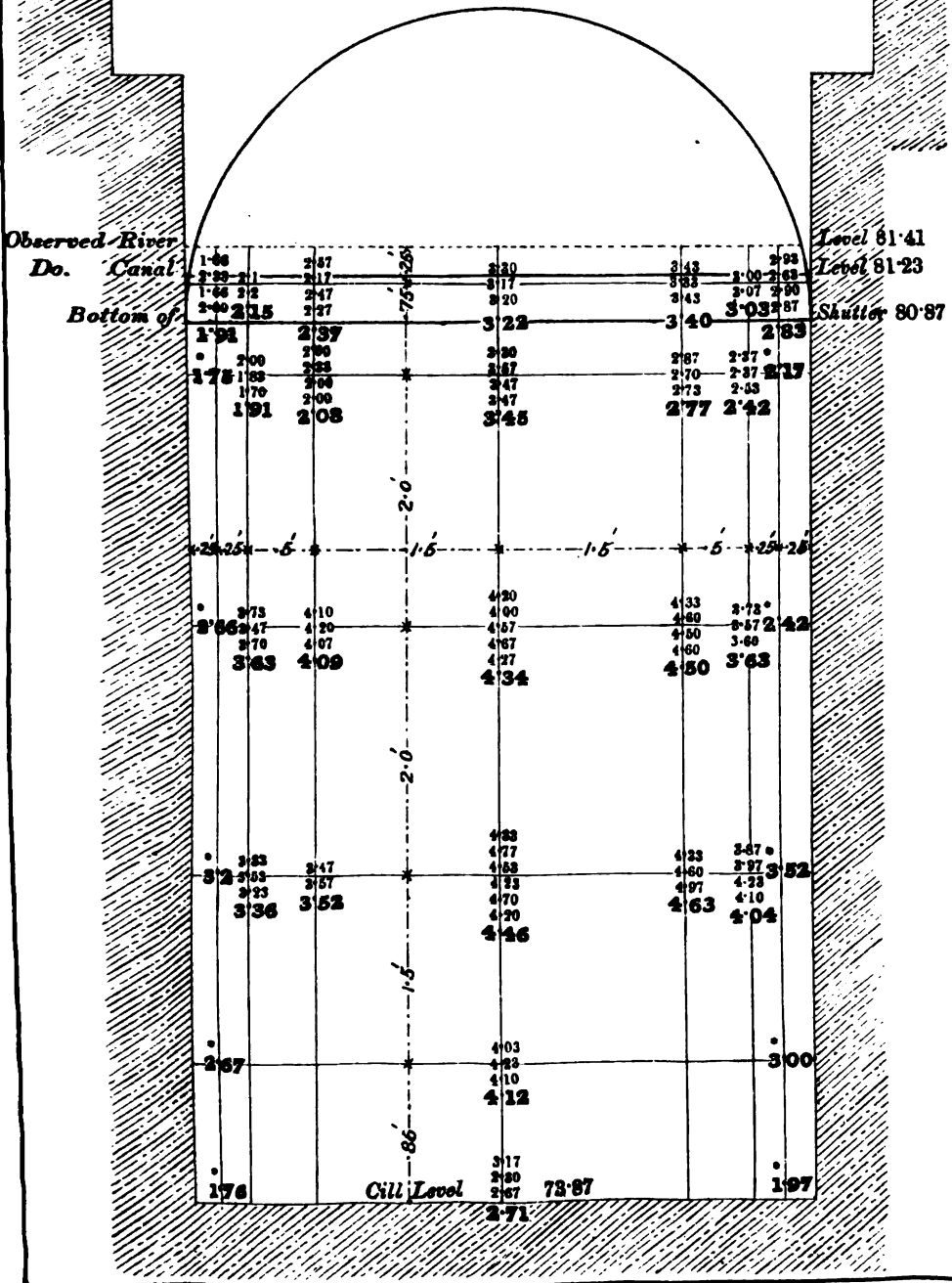


Scale, 15 feet to 1 inch.



NOTE ON EXPERIMENTS MADE TO DETERMINE THE TRUE CO-EFFICIENT OF THE DISCHARGE OF THE HEAD SLUICE OF THE MIDNAPORE CANAL.

CURRENT METRE OBSERVATIONS MADE IN THE MIDDLE VENT OF HEAD SLUICE ON NOVEMBER 4TH 1878



—

No. CCCXXII.

ON THE ACTION OF FALLING WATER.

[*Vide* Plates L.—X.]

By J. S. BERESFORD, Esq., *Executive Engineer*.

THE following papers may prove interesting to the profession as dealing with a subject on which there is not much definite information to be found in books, and regarding which very erroneous views are held by many Engineers.

My attention was first drawn to the subject in 1870 when, as Executive Engineer of the Meerut Division of the Ganges Canal, I had to carry out the repairs to the canal falls in that Division, and complete the protective measures that were considered necessary. These measures were designed in accordance with the theory advanced in my Note on the Keroni weir; and the works then constructed have stood the test of time.

My remarks in the margin of Mr. Eliot's letter, and of Captain Cunningham's note, were written before the Naini Tal experiments were made; but I have allowed them to remain, as they seem to meet fully on theoretical grounds, the objections raised by these gentlemen against my theory, and the proof of it.

The experiments at Naini Tal were conducted some months previous to the receipt of Professor Unwin's memorandum.

List of Papers.

1. Note by J. S. Beresford, Esq., Executive Engineer, on the proposed weir at Keroni on the Ken River, dated 13th April, 1877.

2. Letter No. 461-2 of 30th April, 1878, from the Officiating Chief Engineer, Irrigation Works, to Captain Cunningham, R.E., Thomason College, Roorkee, and John Eliot, Esq., Professor of Mathematics, Educational Department, forwarding Mr. Beresford's Note, and requesting the favour of an opinion on the theory advanced therein.
3. Letter, dated 5th June, 1878, from the Meteorological Reporter, containing Mr. Eliot's reply.
4. Letter, dated July 1878, from Captain A. Cunningham, R.E., in charge of the Hydraulic Experiments, Roorkee, forwarding a Note by him on Mr. Beresford's "Note on Keroni Weir."
5. Captain Cunningham's Note.
6. Memorandum on the Keroni Weir by Professor W. Cawthorne Unwin, Royal Engineering College, Cooper's Hill.
7. Description of Experiments conducted by Mr. J. S. Beresford, at Naini Tal, in October 1878, to determine the intensity and distribution of the pressure of a jet of water against a fixed plane surface.
8. Results of Mr. Beresford's Experiments.

Note by J. S. BERESFORD, Esq., Executive Engineer, on the proposed Weir at Keroni, on the Ken River, dated 13th April, 1877.

The drop below this weir will be so much greater than we are accustomed to, that the ordinary rules of construction are probably not applicable. The only definite rule relative to falls, that I am aware of, is that formed by the late Colonel Dyas, after experimenting on the Bari Doab Canal falls. It is

$$x = \sqrt{h} \sqrt[3]{d}$$

Where x is the required depth of cistern.

h is the height of fall from surface to surface.

d is the full supply depth in channel.

It seems that cisterns made on this rule have stood without repairs.

It is quite an empirical rule, and probably not applicable to the case in question, even were it thought necessary to cut a cistern in the granite, or that the latter were thick enough to admit of its being done. The

form of the equation, too, may be objected to in general application, as the depth of channel d , may vary very much according to circumstances, all the other conditions of fall remaining the same. However, I assume that a cistern is not to be used, and that the question is, will the granite stand the action of the water under the different conditions given.

2. *Fig. 1* represents the two extreme conditions of fall. The dotted lines indicate the water levels of full discharge, and the full lines the same of low discharge. With full discharge the drop over weir will be 16.5 feet, and the depth on floor 65 feet (445.00 — 380.00), so that the floor in this case would seem to be quite safe; the bed some way down, however, will be subjected to a great scour. The other extreme case is the one to consider so far as the granite floor is concerned, *viz.*, when the drop will be 61 feet (449.00 — 388.00), and the depth of water on floor only 8 feet (388.00 — 380.00).

3. Before going further, I may state what I consider to be the action of water on a fall floor. It has been described as similar to that of a battering ram or pile engine. This was Sir Proby Cautley's view, according to which he decided on the ogee form of fall for the Ganges Canal. He found that the ground shook with each stroke of a pile engine, using an ordinary ram and no great fall; and reasoned that the continual action of a much greater weight of water would be very destructive to a canal fall. I think it can be shown that this view is not correct. The effect of a ram falling on a pile can be increased in two ways, *viz.*, either by causing the ram to fall a greater height, or by increasing its weight. In any one case of falling water, the height is the same; but in comparing its effect with that of a ram falling the same height, what quantity or weight of water is to be assumed as acting? The water at A, *Fig. 2*, striking the floor, is not affected by that at B, as, being everywhere a practically free fluid, each particle moves according to a certain law, almost independently of the adjacent particles (I say almost, as water is not a perfect fluid, but is more or less influenced by internal friction and slight cohesion). The difficulty of fixing the proper mass or quantity striking the floor in the form of a ram at once presents itself. Is a column 10 feet high or one only 1 inch high to be taken? It is thus seen that the effect of falling water cannot be compared with that of a falling rigid body. The result, however, will be of the same nature if, in *Fig. 2*,

we conceive the column of water AB suddenly converted into ice; cohesion will then be so far established that the parts A and B will strike at practically the same time, and affect the floor much in the same manner as a ram.

4. A cubic foot of stone, in the form of a boulder, falling a height say of 10 feet on a brick floor, will probably crush or break a brick or two; the same boulder pounded into sand, put into a bag, and let fall the same distance, will do no harm.

5. Rankine, in Art. 406 of his "Applied Mechanics," defines a *current* as "a stream bounded by other portions of fluid whose motions are different," and a *jet* as "a stream whose surface is either free all round, or is touched by a solid in a small portion of its extent only." From this it is clear that a *jet* of water, being unimpeded by the other particles of fluid, is capable of exerting more action on a surface than a current; hence, we shall be on the safe side if we consider the case of a jet. In Art. 648 of the same work, the author investigates the result of a jet striking a fixed surface, which he shows to be a pressure, that, in the case of a plain surface, *Fig. 3*, is equal to the weight of a column of the fluid having the area of the cross section of the jet for its base, and a height equal to twice the height due to the velocity of the jet; and in the case of the jet striking a hemispherical surface, *Fig. 4*, just twice this pressure. In both cases this gives the *total* pressure on the surface, but the *intensity* of the pressure at any given point is quite another matter, not alluded to by Rankine, but which is the important element in dealing with waterfalls. It will be found that the *intensity* of the pressure cannot be more than that simply due to a column of fluid of a height equal to *once* the height corresponding to the velocity. This is proved experimentally, in the case of Pitot's tube, *Fig. 5*. If this tube is placed in a stream or jet, with its bent end against the current, the water will rise in the perpendicular part to a height equal to the height due to the velocity of the stream. Hence its use as an instrument for measuring velocities by an inverse process.

In *Fig. 3* the total pressure is distributed over a portion *ab*, of the surface, much greater than the sectional area of jet; and in *Fig. 4* there is pressure over the whole curved surface due to the centrifugal force of the water, but the actual intensity close to where the jet first strikes, as in *Fig. 3*, is hard to determine, from not knowing the curvature of

each film of water; however, that it cannot exceed what I have stated, can be proved indirectly on the principle of energy.

6. It is hard to get rid of the notion that water acts in the same manner as rigid bodies when falling, and not as a steady and calculable pressure. The noise of the falling water, too, is very misleading. But when there is most noise, there is generally least damaging action.

7. It may be noticed that drops of fallen water often rise much above the source from which the water has fallen. The explanation of this is that water does not always fall in a connected column, or if it does, the fluid is not always diverted in the same direction, hence there are eddies or whirls; and jets or currents moving towards each other may meet, thus giving a greater *relative* velocity than that due to the fall, and consequently, owing to the partial cohesion of water, creating a corresponding pressure, momentarily capable of squeezing out a few drops with a velocity that will cause them to rise much above the source, the pressure or head increasing as the square of the relative velocity just noted. This action is, however, very limited, as shown by the small quantity of water raised above the source in the form of drops. But the floor of a masonry fall being stationary, the relative velocity between it and the water can never exceed the velocity due to the fall; and hence the floor has never to bear more than a corresponding pressure.

8. From the foregoing my idea is, that *the greatest effect of falling water on any part of a floor is a simple pressure which can never exceed, in intensity, the pressure of a column of water of a height equal to the height due to the velocity of the water at the moment it touches the floor, and that this pressure is liable to be exerted in all directions.*

I believe that floors paved with stones sufficiently heavy (after allowing for buoyancy of the water) to resist this cannot possibly fail.

9. It is difficult to say what the velocity of falling water really is by the time it reaches the floor, as on account of resistance of the air and of the back-water, the theoretical velocity is greatly modified; but in the worst case, *viz.*, when there is no back-water on the floor, the velocity can never be more than that due to the total drop, coupled with the mean horizontal velocity of approach: this gives a resultant velocity in an inclined forward direction; but in high drops the horizontal component may be neglected.

10. *Fig. 6* represents a drop; A and B are blocks of stone. So long

as the joint between A and B is quite close or filled with good cement, the water plays on the outside without any bad effect, causing but a simple pressure on the upper surface of the floor at this point. But suppose that the mortar is bad and gets washed out, or the stone gets loosened from the blow of a floating log, a film of water finds its way under the stone; once this film gets directly connected with the falling water, it is instantly under the influence of the pressure caused by the same, and the stone is probably blown out. It is possible that the full intensity of the pressure will not be thrown on the lower side of B, as the joints may leak and let the water escape, thus modifying the pressure to an extent measured by the head due to the velocity with which the escaping water flows through the joint; but in calculating for a floor that is to last, the worst conditions of the case should be assumed. The stones directly under the falling water are not the ones likely to be injured, being rather kept in place by the pressure, but the stones close by, such as A and B, are in the worst position.

11. Six out of seven stone floorings laid on falls in the Meerut Division, Ganges Canal, in 1869, failed. One floor at Dásna, 55' x 20", was moved down bodily a distance of 10 feet from the tail of the ogee, without a stone leaving its place, and some of the other floors were similarly moved forward in two or three pieces. Had the stones not been well cramped, they would hardly have kept so well together; but the movement showed that *deep*, and not merely broad, stones were required. The one floor that stood at Bhola was, on an average, 6 inches thicker than the other floors, having been laid first, and with the best stones.

12. Then it appears to me that there are two ways in which a floor may be protected—

I. By covering it with very deep blocks of hard material laid dry, having open joints between; the wider these joints are the better, provided they are not so wide as to admit of a current strong enough to scour the bed on which the blocks rest; the proper depth of such blocks would be difficult to calculate, but probably should not be less than one-third or one-fourth of the theoretical depth found as above.

II. By covering it with a layer of hard material, so well jointed as absolutely to ensure the falling water never getting under the layer, and strong enough—that is, thick enough—to bear the pressure due to

the fall without breaking across, should the material be imperfectly bedded.

There is a practical difficulty in carrying out the first plan from the size of the blocks required, and trouble in laying. The second plan can be resorted to, and only means using ordinary hard stone, laid in cement that will ensure perfect water-tightness. However, from the ordinary stones not being massive enough, a blow from a floating log may derange the best laid floor, by shaking the stones and opening the joints so as to admit the water, thus leaving the blocks in a condition under which they were not calculated to stand.

13. I believe many of the old brick floors on the Ganges Canal would have stood, but for floating logs that shook the top courses. The floor of Chataura fall, *Fig. 7*, which smashed very badly in 1869, was simply two flat courses of ordinary brickwork and one course on edge, resting on 4 or 5 feet of small country bricks in very bad earth lime that never set. This under-masonry would not stand with a vertical face when being removed, and was easily dug out. There was no appearance of an arch as shown in the Atlas design; perhaps it was not considered necessary at time of building. But these floors withstood for 15 years the action due to from 1,000 to 5,000 cubic feet per second falling through a height of 9 feet over a crest 200 feet long, and only failed when the top crust got broken; and the Delhi stone below the new cross walls is now resting on the original good crust with very inferior stuff below.

14. One point remains to complete my argument. What becomes of the energy of so large a body of water falling a great height, if it does not expend itself in breaking up and battering the floor in the form of a ram? In a pile engine the full energy of the blow does not go to drive the pile, but some of it is lost in compressing the head, resulting in the production of heat. In the case of falling water the whole power goes in raising the temperature of the water in the proportion of 772 foot-pounds to each pound of water raised one degree Farh. Thus, water after falling 61 feet will be raised in temperature by $\frac{61}{772}$ = say, in round numbers, $\frac{1}{13}$ th of a degree, Farh.

The result of all the agitation that one sees below a fall is the production of heat. The water in the channel a few furlongs below the fall leaves in apparently the same condition and with the same velocity that it approached it above, many thousand foot-tons of power having been

expended between, without showing any *visible work*. The work, however, is done, and consists in raising the temperature of the water.

15. Water acts in another manner, which I have not alluded to, *viz.*, by abrasion. This action is slow, and its effect depends on the hardness of the substance on which the water rubs. But in time the hardest material shows signs of wear.

16. Mr. Lewis D'A. Jackson, in the article on Canal Falls, beginning at page 207 of his "Hydraulic Manual," (3rd Edition,) speaking of vertical falls with water cushions (pages 212-214), states that the result of the formula

$$d = 1.5 \sqrt{h} ; \sqrt[3]{h}$$

which is a modification of the one given in paragraph 1 of this Note, has not been accepted by the Madras Engineers in the case of the Masur reservoir dam, where the fall is 43.5 feet. The formula gives a cistern 18 feet deep, while one 33 feet deep has been adopted. But I presume the extra depth given was a mere matter of opinion. A second instance is quoted, where the formula gives a depth of 12.54 feet, while in hard rock 16.19 feet has been allowed : this, I take, was also a matter of opinion, and the hard rock would probably have stood without a cistern at all. The Rájáh natural fall at Gairsuppa is mentioned as a case in point. It has a total drop of 829 feet, and the water has scouped out for itself a cistern 130 feet deep, against a depth of 72 feet, as given by the formula. But in considering the depth of cisterns below natural falls, the element of time should not be forgotten. The cistern below the Rájáh fall may be the result of a scour extending over a hundred thousand years or more. If the average wear per year were only $\frac{1}{100}$ part of an inch, this would give a cistern over 83 feet deep.* But there is no saying how long the period has been, and the abrasion at the bottom which (owing to the depth) is now very little, must, I should say, have been considerable in the earlier stages, especially if pieces of broken rock got into the cistern. One action of moving water, however slow the motion, is to wear away the surface on which it flows and rubs. Where the water is pure, the wear is less than when it is charged with silt. But such wear in cases of hard rock is so small, that its effect is not likely to show itself for a long time. However, in time this action will scour out a deep basin.

$$* \frac{1}{1200} \times 100,000 = 83'.$$

17. But the most marked action of water below an artificial fall, built on ordinary earth, shows itself in breaking up the floor in large masses, not in reducing its thickness by steady wear, although even this is apparent on the brickwork of the ogees in some of the Ganges Canal falls. The moral is, use the hardest material procurable (in these parts Delhi stone). Agra stone is little harder, if as hard, as well burnt bricks. But that good brickwork can stand a considerable fall of water for a number of years without either cistern or back-water, as at B, *Fig. 8*, has been proved in the upper sills of the Ganges Canal falls, which have only recently been protected with stone as a precaution.

18. The greatest drop in the case of the Keroni weir will be 61 feet, and as the velocity of approach will be slight, the velocity of the water when it touches the floor may be taken as that due to 61 feet fall, or, in case there should be no back-water (the bed below the granite barrier having been scoured out) a velocity due to a drop of 69 feet. Hence I hold that no greater pressure can come into play on the granite than that of a column of water of a height due to this velocity, *viz.*, 69 feet; that is, a pressure of $69 \times 62.5 = 4,312$ lbs. per square foot. This is the greatest intensity of pressure due to the falling water, and can be easily borne by granite in the mass. But loose blocks of granite beyond the influence of this vertical pressure would theoretically require to be $\frac{4312^*}{108} = 40$ feet thick to ensure not getting blown out. However, from the fact that the open joints would let the compressed water escape, the theoretical result may be considerably reduced, depending on the width of the joints. Thus, if the joints are open at all, it is better that they should be wide, so as to let the water escape (as at *a* and *b*, *Fig. 6*) and ease the upward pressure on the stone, the worst case being one or two open joints near the falling water and all the rest closed.

19. Now, in the proposed weir on the Ken River, there is a natural barrier of granite of, I presume, a considerable depth; and, if not all in one piece, at least consisting of very large blocks, so there would seem to be all the favourable conditions necessary to standing, even with a much

											lbs.
* Weight of granite in air, ...	...	...	...	...	...	...	...	...	...	...	170.5
„ of water, ...	...	...	...	...	...	...	...	...	...	...	62.5
„ of granite in water, ...	...	...	...	...	...	...	...	...	...	...	108.0

greater drop than is proposed; hence, provided the barrier is not too thin to admit of removing faulty pieces, I see no reason why it should fail: 4,312 lbs. per square foot is the greatest pressure it can be subjected to.

Note.

The concluding portion of paragraph 5 appears to require some explanation. The previous paragraphs go to show that the action of falling water is a steady pressure, the total amount of which is calculable on the principles laid down in Art. 648 of Rankine's Applied Mechanics, but the intensity of this pressure at different points of the surface acted upon is a matter not alluded to in any book on the subject that I have seen.

In the present case it is only necessary to prove that the intensity cannot exceed a certain limit. Now assuming my reasoning in paragraph 10 as correct, and supposing that the film of water under the floor is liable to a greater intensity of pressure than that of a head h , due to the velocity with which the falling water meets the floor, say to an intensity corresponding to a head h' , equal to $h + x$. Then—

$$h' = h + x = \frac{v^2}{2g} + x$$

$$\text{Let } x = \frac{2vd + d^2}{2g}$$

$$\text{Then } h' = \frac{v^2 + 2vd + d^2}{2g}$$

Again, suppose a small hole drilled in the floor, a quantity of water per second, weighing say w will, neglecting friction, pass through the hole with a velocity $v + d$ due to the intensity of pressure h' .

If W is the total weight of the quantity of water meeting the floor per second, and if, for simplicity, it is assumed that there is no loss by friction, the water after meeting the floor will leave in its new direction with unchanged velocity, and therefore (before the hole is drilled) with an energy per second of

$$E = W \times \frac{v^2}{2g}$$

But after drilling the hole a quantity of water weighing w will pass out with a velocity $v + d$, while the rest, viz., $W - w$ will leave with a velocity v as before, the combined energies per second being

$$E' = (W - w) \frac{v^2}{2g} + w \times \frac{v^2 + 2vd + d^2}{2g}$$

$$= W \times \frac{v^2}{2g} + w \times \frac{2vd + d^2}{2g}$$

$$\text{Gain of energy } E' - E = w \times \frac{2vd + d^2}{2g}$$

which is impossible, therefore $d = Q$, and $h' = h_1$, or in other words, h' cannot exceed h_1 .

Letter No. 461-2 W, dated 30th April, 1878, from the Officiating Chief Engineer, Irrigation Works, N.-W. Provinces. To CAPT. CUNNINGHAM, R.E., Thomason College, and JOHN ELIOT, Esq., M.A., Professor of Mathematics, Educational Department, Bengal.

Has the honor to forward a paper by Mr. J. S. Beresford, on the proposed masonry weir across the Ken river at Keroni, in Bundelkhand, and to request that $\frac{\text{Captain Cunningham}}{\text{Mr. Eliot}}$ will kindly favour the Chief Engineer with his opinion on the theory, advanced by Mr. Beresford, of the action of falling water, and the application thereof to ordinary waterfalls.

*From—J. ELIOT, Esq., Officiating Meteorological Reporter to the Government of India,
To—The Officiating Chief Engineer of Irrigation Works, N.-W. Provinces.*

Dated Calcutta, 5th June, 1878.

SIR,—I regret that owing to my taking up a new appointment and going on a short tour of inspection at the beginning of the month of May, your letter No. 462 W and enclosure, did not reach me until a few days ago, and as I have no works of reference on hydraulics with me, my reply will be only a partial one.

I should suggest the submission of the paper to Captain Cunningham of the Thomason Civil Engineering College, who has for some

time devoted himself to the theoretical and experimental sides of the important subject of water motion.

The first point in Mr. Beresford's paper with which I only partially agree is in paragraph 3. He is correct in his opinion that the action of the continuous falling water is not the same as that of the impact of an equal mass through the same height. The action of the falling water is essentially continuous, and it would be incorrect to substitute for this the discontinuous action of one or more falling masses.

Para. 5.—I can give no opinion upon it at present, as I have not got a copy of Rankine's *Applied Mechanics* with me.

Para. 8.—I cannot agree with this, Mr. Beresford's rule is simply the old hydrodynamical rule¹ for resistance produced by a moving fluid upon a fixed obstacle, and both the concerned, but my remarks refer to proof and rule have been acknowledged to be so defective, as to be quite a different thing, *viz.*, intensity of pressure, which I hold cannot be omitted from the last edition of the Cambridge Text-book on Hydromechanics (Besant's).

¹ Yes, old rule so far as determination of total pressure or resistance is concerned, but my remarks refer to quite a different thing, *viz.*, intensity of pressure, which I hold cannot exceed the limit stated.

J. S. B.

The rule is resistance or pressure due to resistance = $\frac{mv^2}{2}$, which in this case $\frac{m \times 2gh'}{2} = mgh = wh$, that is, equal to the pressure of a column of water of a height equal to the height due to the velocity, or in this case, the height of the fall. This rule is

undoubtedly much nearer to the truth than making the action equivalent to that of a falling mass. But even Mr. Beresford's rule, as he himself apparently admits in Article 9, is imperfect, and founded upon doubtful reasoning. For it is evident that the pressure and action of that height of still water does not produce the

² On the contrary, I think a much same effect² either in attrition or in greater effect in blowing out; for I blowing out, which occasionally occur of no case in which a mass of cures. The motion of viscous fluids masonry corresponding in weight per has not yet been subjected, from the unit of horizontal area to the possible inherent difficulty of the investigable hydrostatic pressure, has been tion, to mathematical analysis. But blown up by water falling with a there are several reasons why Mr. velocity due to this pressure.

J. S. B. Beresford's rule seems to me to give certainly much too small a pressure. 1st, Taking the analogy of a falling solid mass: an inelastic mass falling upon any portion of the earth's surface, produces a certain action during the short interval it requires for the falling mass to be brought to rest. If the same mass of an elastic substance falls, the action is greater, the greater the elasticity of the body, and if it is perfectly elastic, the action is double what it is in the case of an inelastic body; consequently the pressure produced by the fall of any solid mass depends upon its elasticity as well as its mass. Mr. Beresford has entirely left this element out of ac-

³ Mr. Eliot has again apparently count,³ although he states that the misunderstood me. He here refers water rebounds, and endeavours to to the total action during impact, and explain why some particles of the

water rise to a much greater height not to the maximum intensity of than the top of the fall.

Again, Mr. Beresford leaves out pressure at any moment, which depends much more on the *modulus of* another important element, the area *elasticity* than on the *co-efficient of* over which the water meets the bot- *elasticity*, which is evidently what Mr. tom after its descent; *Fig. 2* and Eliot alludes to. Thus take the case *Fig. 6* both show (and show correct- of equal weights of soft iron and ly) that the water in falling (or the India rubber striking a perfectly hard stream leaves) will be approximately surface with the same velocity. The parabolic, and that under the pecu- *total* mechanical action during im- liar circumstances, increasing veloci- pact would, as Mr. Eliot truly says, ty during descent, and very slight be greater in the case of the India differences in the height of the fall, rubber, but the pressure between the the thickness of the falling water in surface and the impinging body would the horizontal direction will dimin- at any moment be less in the case of ish. The action and rate of pres- the India rubber in the inverse ratio sure, it is evident, will depend very of the relative yield or compression considerably upon the area⁴ on which of the rubber and iron during impact. the water falls: it would be quite J. S. B.

easy to calculate the amount of the ⁴ Rather upon the velocity with contraction (from the parabolic paths which the water meets the floor? described). It is very evident that J. S. B.

the increased rate of pressure due from this action may be very considerable.⁵

⁵ Yes, because the greater the Without enumerating one or two contraction, the greater must neces- minor objections, I think the above is sarily be the velocity, but the velo- sufficient to show that Mr. Beresford's city can never exceed that due to the conclusion on paragraph 8 is not only fall.

open to very grave objections, but

J. S. B.

that it entirely fails to explain that enormous lifting power observed.⁶

⁶ The lifting power observed is The rate of pressure is undoubtedly really never so great per square foot much greater than the pressure due as my rule gives. to the height.

J. S. B.

The velocity of the falling water, as Mr. Beresford remarks, is a very

difficult question. If the falling water breaks up into drops, then there will be a terminal velocity depending on the magnitude of the drops. But in the case of small falls, when the volume of water is considerable, probably the mass falls continuously, and in this case the resistance of the air will produce a slight effect, so that if v be the enclosed velocity at head of even 1 v' at

$$V^2 = v'^2 + 2gh \text{ approximately.}$$

Drop 61 feet

$$v^2 = 2gh = 64 \times 61$$

$v = 64$ feet per second very nearly, or $\frac{64 \times 60 \times 60}{5280} = 40$ miles per hour, and in the whirl that is set up, it is possible that the motion may be

'Can never be greater relative-even greater than this.'
ly to the floor. The eroding action of water moving with so great a velocity, is necessarily very great.'

'This is quite another matter, with which I deal in paragraph 15 of my Note on the Keroni Weir. Hence, 1st, the absolute necessity for the most perfect masonry and for the employment of the best cement, to prevent the erosive action at the joints.

J. S. B. 2nd. The desirability of increasing the area over which the water falls, so as to keep the rate of pressure due to fall as low as possible.

'Both of these methods have been tried in practice, with success; but methods of attempting to diminish making a deep cistern where the the action or the fall: 1st, to have a spring line is near the surface is often large hollow at the base so that there prohibitively expensive. Besides, the may be a considerable cushion of

water to receive the falling mass. object of my Note was to try and in-
The water falling on this will distri- vestigate the maximum effect of fall-
bute the pressure over the whole of ing water when no cistern is provid-
the hollow of basin, instead of allow- ed. Present fall construction is
ing it to fall upon only a portion of based on no scientific principle, and
the bed, which would give rise to so no two Engineers design alike.
very unequal pressure on this bed
masonry, and which I imagine is much
more dangerous than considerable
pressure equally distributed over the
whole.

J. S. B.

2nd. To break up the falling mass
of water partially into spray. The re-
sistance to falling in this case is much
greater, and the final velocity after a
considerable fall, therefore much less.
The area over which it falls is much
greater, and hence the rate of pres-
sure consequently less.

From—CAPT. ALLAN CUNNINGHAM, R.E., *Thomason College, Roorkee.*

To—*The Chief Engineer, N.-W. P., P. W. Dept., Irrigation Branch.*

Dated Thomason College, Roorkee, July 1878.

SIR,—I have the honor to submit the Report asked for in your No.
461 W of 30th April 1878, on action of falling water as advanced in
Mr. Beresford's printed Note on the Keroni Weir.

Some delay has occurred by my having to ask for further informa-
tion.

I return now all the papers, viz.—

- | | |
|--|--|
| 1 Copy Mr. Beresford's printed Note, received with your No. 461 W. | |
| 1 Copy Mr. Beresford's printed Note, | } received with demi-official
Note from Mr. Beres-
ford. |
| 1 Copy MS. Addendum to ,, | |
| 1 Copy Mr. Eliot's Note on ,, | |
| 1 Demi-official note from Mr. Beresford; | |

and am sorry that I have not been able to advance the question
much.

Mr. Beresford's printed "Note" on Keroni Weir.

References to paragraphs of printed Note. By CAPT. ALLAN CUNNINGHAM, R.E.

B. para. 1. Formula $x = \sqrt{h} \cdot \sqrt[3]{d}$, for finding depth of cistern.

This formula is probably applicable only to those cases within a limited range for which it was proposed; the right hand expression being of order $\frac{1}{2} + \frac{1}{3} = \frac{5}{6}$, the equation is not explicitly homogeneous, so that it is probably empirical.

Minimum Water on Floor.—This appears to be 8 feet, so that the

B. para. 2. floor can apparently never be exposed to the direct action of the full fall of water.

Effect of a Fall.—The first effect is an Impact; after which the permanent effect must be admitted to be SIMPLE

B. para. 3. PRESSURE, liable, however, to moderate variation in successive instants in consequence of the unsteadiness of the fall itself.

[If the fall be liable to bring over drift wood, boulders, or rocks, the effect of these is Impact].

Effect of Jet.—The permanent effect of a Jet is stated in Rankine's Applied Mechanics, Art. 648, to be a pres-

B. para. 4. sure whose magnitude depends principally on the angle through which the current is diverted by the obstacle, and is

Case i. Jet $\perp^r$ to a plane.—Total Pressure = weight of a column of the Jet of height equal to twice the height due to the velocity, (if the current be *diverted* 90° .)

Case ii. Jet $\parallel$ to axis of a hemisphere.—Total Pressure = weight of a column of the Jet of height equal to four times the height due to the velocity, (if the current be *reversed*.)

These results depend upon a certain theory, (explained in Art. 648 of Rankine's Applied Mechanics,) which must be admitted to be imperfect.

The former result has been amply verified by experiment. It appears* from experiment that the full diversion of 90° in a Jet $\perp^r$ to a plane does not take place unless the plane area be at least six times the cross-sectional area of the Jet, and that the Jet then produces its maximum Total Pressure, of amount above stated; and that for lesser areas

* Weisbach's "Mechanics of Engineering", (Ed. of 1877), Art. 449.

the diversion of the current is less than 90° , and the Total Pressure less; and that in case of a Jet $\perp$ to a plane area equal to cross-section of Jet, the current is diverted through an acute angle only, and the Total Pressure reduced to half its former amount.

These results of experiment are summarized below:—

	Size of Plane.	Angle of diversion of current.	Pressure on Plane = weight of a column of the Jet whose length is
Jet perpendicular to Plane,	$> 6 \times \text{Jet-section,}$	$90^\circ,$	$2 \times \text{height due to velocity. [This is the maximum effect].}$
	$< 6 \times \text{Jet-section,}$	$< 90^\circ,$	$< \text{the above.}$
	$= \text{Jet-section,}$	Acute,	Height due to velocity.

Mean and maximum pressure-intensity.—The mean pressure-intensity is of course the Total Pressure $\div$ the area under Pressure; and may, therefore, be at once derived from the above Results. But there are no *data*—as far as the present writer knows—from which the maximum pressure-intensity could be inferred: so that its probable amount can be only roughly guessed at by aid of some hypothesis as to the distribution of pressure. The only probable hypothesis seems to be that the pressure is *uniformly varying*, in which case its distribution over the plane would be graphically represented by a cone in the case of an isolated cylindric jet, and by a wedge in case of a very wide flat jet, from which the relation of the maximum and mean pressure intensities are at once inferred as below stated.

Jet.	Graphic representation of Pressure.	Maximum pressure-intensity.
Cylindric jet,	Cone,	$3 \times \text{mean pressure-intensity.}$
Wide jet,	Wedge,	$2 \times \text{mean pressure-intensity.}$

Combining these with the preceding, are obtained the following values of mean and maximum pressure-intensity.

Jet.	Impingence.	Area of Plane.	PRESSURE-INTENSITY = TO PRESSURE OF COLUMN OF HEIGHT.	
			Mean.	Maximum.
Cylindric,	$\perp$ to Plane,	$\left\{ \begin{array}{l} > 6 \times \text{Jet-section,} \\ = \text{Jet-section,} \end{array} \right.$	$\frac{1}{2} \times \text{height due to velocity,}$ Height due to velocity,	Height due to velocity. $3 \times \text{height due to velocity.}$
Wide and Flat,	$\perp$ to Plane,	$\left\{ \begin{array}{l} > 6 \times \text{Jet-section,} \\ = \text{Jet-section,} \end{array} \right.$	$\frac{1}{2}$ height due to velocity? Height due to velocity?	$\frac{3}{2} \times \text{height due to velocity?}$ $2 \times \text{height due to velocity?}$

The experimental Results above quoted were *probably* derived from experiments on *cylindric jets only*, so that their applicability to wide flat jets is doubtful. The authorities are quoted in Weisbach's *Mechanics*,* but the author has not been able to procure them; without consulting them this question must remain doubtful.

Maximum pressure-intensity, Mr. Beresford's limit.—In the printed B. paras. 5 and 8. Note, paragraph 5, it is stated—

"It will be found that the *intensity* of the pressure cannot be more than simply that due to a column of fluid of height equal to *once* the height corresponding to the velocity,"

As to this, it is further stated, *ibidem*.

1°, "This can be proved theoretically."

2°, "And is proved experimentally in the case of Pitot's tube."

3°, "That it cannot exceed what I have stated, can be proved indirectly on the principle of energy."

Now, the first statement has been cancelled from an amended copy of the printed Note, so may be dismissed without remark.

As to the second statement, it is *doubtful* how far Pitot's tube is a fairly applicable instance, for the column of water in the tube is balanced not by the pressure of an isolated jet, but by the pressure of a limited part of a large current.

The proof of the third statement contained in the MS. accompani-

* Art. 449 (Ed. of 1877).

ment to the printed Note is decidedly defective. It amounts briefly to this—

“A weight W of water falls on a floor from a height h , and arrives “with velocity $v = \sqrt{2gh}$, and with kinetic energy Wh . If a portion thereof of weight w develop a pressure on the floor equal to a “head $h' > h$, it is said to leave with velocity $v' = \sqrt{2gh'} > v$; and “the rest $(W - w)$ of the water is said to leave with the velocity v of “arrival unchanged, so that the final total kinetic energy appears to be “ $wh' + (W - w)h$ which is $> Wh$ the kinetic energy of arrival, “which is of course impossible.”

And the inference drawn is that—

“A pressure of head $h' > h$ cannot be developed.”

But the fact is that if the weight w leave with velocity $v' > v$, the rest of the water $(W - w)$ cannot keep the velocity of arrival (v) unchanged, but must leave with *diminished velocity*, so that both

(a). Total water leaving = Total water arriving.

(b). Total energy of leaving }
including heat effects } = Total energy of arrival.

Thus the step wherein the weight $(W - w)$ is made to leave with velocity of arrival (v) unchanged is a mistake, and the final inference therefore falls. *

The argument from use of Pitot's tube appears then to be the only one entitled to weight, and in the doubt as to the applicability of the Results at end of paragraph 5 (above) to case of a wide flat jet, like a waterfall, it appears to the author that the value of the maximum pressure-intensity based thereon, *viz.*, that it is equal to the pressure of a head *equal to the height due to the velocity* rests on evidence quite as good as those Results.

Professor Tyndall's explanation† of the roar of a waterfall is that it is due to the explosion of air bubbles enclosed in and carried down by the water.

The same explanation‡ is given of the spray thrown out, up, and around by a waterfall.

* But this is just my line of reasoning. I show that if a certain excess of pressure is developed, an absurd result follows; hence, I conclude that a pressure in excess of a certain limit cannot be developed.

J. S. B.

† English Cyclopædia, Art. Waterfalls.

‡ English Cyclopædia, Art. Waterfalls.

The minimum depth of the water on the floor being 8 feet, (see paragraph 2 above) the maximum pressure-intensity above discussed can never occur.

If the floor be liable to internal fissures, with horizontal or oblique lamination, *anywhere near the surface*, it would seem that it must eventually be blown up in detail, unless the fissures have free communication with the surface in all directions.

Memorandum on the Keroni Weir. By PROFESSOR W. CAWTHORNE UNWIN.

Some papers on a proposed weir at Keroni, with an exceptionally high fall, having been forwarded to me by Mr. W. J. Wilson, with a request that I should express an opinion on the views discussed in them, I now have the pleasure to forward a memorandum on the subject.

It appears that the proposed weir is a nearly vertical faced weir, and that the water will fall with a clear overfall on to the granite foundation of the weir. In certain conditions of the river, the fall from surface of head water to granite foundation may approach or reach a height of 70 feet, and it appears that in those conditions the protection afforded to the foundation by the water cushion below the weir will be comparatively slight. Hence has arisen a question as to the strength of the natural granite base on which the weir is built to resist the impact of the falling water.

The most important of the papers sent to me appears to be the memorandum of J. S. Beresford, Esq., and it may be as well to state at once that that memorandum appears to me to contain a thoroughly practical view of the action of the water, and the conclusions arrived at are, so far as I can judge in the main, perfectly sound. I should perhaps dissent from some portions of the reasoning, but this does not affect my belief that the general conclusions are accurate.

Two questions arise at the outset in studying the action of the falling water on the foundation of the weir.

- (1). What is the total force exerted by the water.
- (2). In what way is that force distributed.

I. Total pressure on weir floor.

The resultant force on the floor below the weir must (neglecting

friction) act normally to the floor, and its amount is given by a very simple mechanical principle very easily applied in the case of a fluid stream, all the parts of which have, before and after impact, very approximately the same velocities and directions of motion. *The total force is equal to the change of momentum per second, estimated in a direction normal to the floor.*

Hence if Q = quantity of water passing over weir per second in cubic feet.

v = its velocity immediately before impact, which in this case is sensibly normal to the floor, in feet per second.

G = weight of water per cubic foot in lbs.

g = acceleration of gravity.

Then the total force acting on the floor of the weir is

$$P = \frac{G}{g} Qv ;$$

for this is the momentum per second delivered normally to the floor, and after the impact the water flows parallel to the floor and has no momentum in its original direction. Friction would only modify this result so far as it tended to diminish the velocity of portions of the impinging water.

If the falling stream impinged on a plane extending in all directions, the above result would involve only one assumption, not certainly fulfilled by the conditions of the problem. That assumption is, that nothing in the nature of a rebound took place from the floor on which the water impinged.

If there were such a rebound, then there would be a somewhat greater total pressure on the floor. But in the case of an indefinitely extended floor, this action might safely be neglected.

In the actual weir, the floor is bounded near the falling stream by the weir wall, *Fig. 9*, and this may have the effect of causing a greater deviation of a portion of the stream. In that case the total pressure on the weir floor would be somewhat increased, both by the greater initial deviation of part of the stream, and by the subsequent second fall of that portion of the water. It is possible that one advantage of a water cushion below a weir is, that it tends to suppress any reflux of this kind.

II. *Distribution of pressure on the weir floor.*

The problem of the distribution of pressure in a jet striking a plane and spreading in all directions, is one of the highest degree of com-

plexity, and no complete solution can be given at present. A somewhat more restricted case has, however, yielded to analysis. If the jet is supposed to be confined between planes so that the motion is all parallel to one plane, the difficulty of the problem is greatly reduced.

Now in the case of a weir, the side walls prevent lateral motion, and the conditions approach those of the more limited case just mentioned.

I have forwarded to India a number of the *Philosophical Magazine** which contains the most complete statement I am acquainted with of the results thus far obtained in the treatment of this problem.

Lord Rayleigh's paper contains an investigation, on the most rigid mathematical principles, of the action of a stream of unlimited breadth on a plane immersed in it, on the assumption that the deviation of the fluid is always parallel to a given plane. He has determined the position in the plane of the resultant pressure and the mean pressure, whatever the obliquity of the plane. He shows that in all cases the maximum intensity of pressure is $\frac{1}{2} \rho V^2$, where V is the velocity of the fluid before impact, and ρ its density, the formula giving the pressure in lbs. per unit of area.

Or if G = weight per cubic foot of the fluid; $g = 32.2$, then the maximum intensity of pressure is in lbs. per square foot.

$$p = \frac{G}{g} \cdot \frac{V^2}{2}$$

The case discussed by Lord Rayleigh is not identically the same as that of a weir with an overfall, but I believe the same limit of pressure is applicable in both cases, and this can I think be shown by reasoning of an elementary kind. Suppose *Fig. 10* to represent a stream impinging on a plane. Each layer of water is more or less gradually deviated, and during deviation exercises a centrifugal pressure in the direction of the arrows towards the centre of the jet. The outermost layer being subject throughout to uniform atmospheric pressure must flow with uniform and unchanged velocity. The inner layers being subjected as they approach the plane to a greater pressure than atmospheric pressure will have a less velocity, and so much less as they are nearer the centre of the jet. But if the pressure at any point exceeds $\frac{G}{g} \cdot \frac{V^2}{2}$ the layers interior to that point will be forced back and flow upwards instead of downwards, which is not possible.

* Vol. II., No. 13.

If it is replied that in some cases water is thrown above the level from which it falls, I should answer that I believe that is only true of very small portions of the whole mass of water, and that it is due to the motion of the water, not being perfectly regular, but to the flow near the bottom of the fall occurring in gushes.* In a very high fall the separation of the falling mass into arrowy jets may be observed, and in the impact of these, instead of the perfectly uniform pressure found above for a stream in perfectly steady motion, a varying pressure will be produced, due to the impact of the successive masses. The mean value of the pressure will be as before, and the range of variation cannot be assigned without some knowledge of the weight of the separate masses into which the water divides. But I apprehend the variation of pressure is not very great, and must be allowed for in a practical way.

If the elasticity of the water causes anything in the nature of a rebound from the plane surface, that may tend also to cause fluctuating of pressure; but I still think that the estimate

$$p = \frac{G}{g} \cdot \frac{V^2}{2}$$

is a perfectly sound basis for engineering calculation, allowing as is always done, a margin for contingencies.

Weir with curved apron.—It seems worth suggesting that if the apron of the weir were curved (*Fig. 11*) the pressure on the base of the weir would become at once perfectly definite in amount and distribution. Let Q be the number of cubic feet falling over the weir per second, then the whole change of momentum per second, which is equal to the resultant force acting at 45° with the horizontal is—

$$p = \frac{GQ}{g} \cdot v$$

Suppose the curvature of the apron circular and its radius r . Then the pressure would be uniformly distributed, and its intensity per unit length of arc would be

$$p = \frac{2P}{\pi r} = \frac{2}{\pi r} \cdot \frac{GQ}{g} \cdot v$$

(The radius would have to be greater than the stream thickness).

Since $Q = Wv$, where W is the section of the stream, and for each foot length of weir $W = d$, the thickness of the stream

$$p = \frac{2}{\pi r} \cdot \frac{G}{g} dv^2$$

* Portions of water will rebound from the floor, partly because of their elasticity, partly lifted by imprisoned air, and these meet the subsequently descending masses.

(The statements above are only approximate, as the gain of velocity due to vertical fall along the curve is neglected).

This would be a return to the ogee form of weir which, in its original application on the Ganges Canal, was not successful. But its failure in that case seems to have been due to other causes than the form of the apron, and the same form has been adopted in other cases with success. For instance in the Henares weir and in the overfall of the Habra dam, described in the last volume of the Minutes of Proceedings of the Institution of Civil Engineers.

Cause of destruction of masonry floor of weirs.—The failure of the flooring of some of the weirs on the Ganges and other Canals has naturally led Engineers to estimate as very serious the violence of the impact of great masses of water on masonry works. It is very much to be desired that the exact cause of failure in these cases should be traced. It appears to me, and this view has already been stated by Mr. Beresford, that in many of these cases the weir floor has been blown up, and not destroyed by direct impact. The mode of action is this, the great pressure at *a*, *Fig. 12*, is transmitted through crevices in the masonry to the underside of portions of the floor over which the downward pressure is small. In this way pressure may be conveyed through exceedingly small interstices, and may ultimately act on large areas, and with a total force of very great amount, and in a direction in which the resistance of the masonry is least. In sketches of the weirs of the Ganges Canal which failed, it is apparently the flat portions of the floor beyond the point where the water ceases to be deviated that have given way. Of course when once a hole is made in the floor, the masonry is attacked in detail, and the comparatively small forces due to the horizontal impact of the stream against projecting portions may be sufficient to continue the destruction, especially when the diminution of the weight of the masonry under water is considered.

Action of Cushions.—It is clear that water cushions can in no way alter the total pressure sustained by the weir floor, in consequence of the impact of the water. Their protective influence must therefore be due to the spreading of the pressure over a wider area, *Fig. 13*.

This lessens the danger of blowing up in two ways. (1). By increasing the downward pressure over a great extent of floor, which virtually adds to the weight of the masonry. (2). By diminishing the intensity

of the pressure at the mouths of the crevices communicating with the water below the floor.

Scour of water.—I am unable to give any opinion as to the amount of direct scour of hard rock surfaces likely to result from the horizontal flow of the water. I once observed hard brass filed away by a jet of water flowing over the surface with a velocity due to about 150 feet of head, but I presume that action was due to particles of sand carried by the water. The scouring of pot holes in the beds of streams of hard rock, as for instance in the granite of Eskdale, seems again to be chiefly due to pebbles kept in motion by the water.

Captain Cunningham's estimate of the intensity of pressure on the assumption of uniform distribution.—I am not able to attach much importance to the arithmetical results Captain Cunningham has obtained by assuming a uniformly varying distribution of the pressure, and I suppose that he also puts them forward rather as helps to understanding the way in which the water acts than as having any quantitative accuracy. It is pretty certain that the distribution of pressure is not uniformly varying, and the area on which it is to be taken as acting is not experimentally known. In the cases in which the area of the plane is identical with that of the cross-section of the jet, there is, however, a further erroneous assumption in the calculations which lead to the result that the maximum intensity of pressure may be that due to a head twice or three times that due to the velocity. It is assumed that with these small planes the *total pressure* is the same as for more widely extended planes (*Fig. 14*), and this is not the case. If the plane is very small, the total deviation and the total pressure are both diminished.

The argument from Pitot's tube.—The argument from the action of the water in a river or other flowing stream on the column of water in a Pitot's tube is defective for this reason :

In a Pitot's tube immersed in an ordinary current, there is very little pressure due to mutual action of the layers of water in a direction normal to the direction of flow. Each filament has the velocity due to the head h near the tube, and the filament which actually impinges on the orifice of the tube supports a column $h = \frac{v^2}{2g}$ in consequence of its deviation by the tube, and that of some other filaments near it, *Fig. 15*.

At the foot of a weir, however, the streams are not parallel, the mutual pressure of the filaments is very great, and their actual velocity near the

centre of the impinging mass is probably very small in a direction normal to the mouth of the tube. The argument from the Pitot's tube therefore needs some modification to be conclusive.

I think I have now given my opinions on the points referred to me as fully as is necessary to make them intelligible. I have unavoidably written them while somewhat pressed by other work; but I do not think that further consideration would lead me to alter them in any essential respect. At the same time I should like to urge the expediency of some experimental trials of the pressure on the base of large falls. There are circumstances of viscosity, elasticity, &c., which cannot be embraced by theory; and apart even from this some experiment is desirable. Some apparatus like that used by Stevenson in determining pressure of sea waves, or an adaptation of a Pitot's tube to this special purpose, would furnish very useful data.

Description of experiments conducted by MR. J. S. BERESFORD, at Naini Tal, in October 1878, to determine the Intensity and Distribution of the Pressure of a Jet of water against a fixed plane surface.

These experiments were necessarily on a small scale, for, without expensive appliances and much spare time, they could not have been carried out on a large scale. The point to be determined was this.

Supposing a film, or jet of water to fall as indicated in the sketches A and A', Fig. 16, what will be the maximum *Intensity* of pressure at any point on the floor ab or $a'b'$? I maintained in my Note on the Keroni Weir, that it cannot exceed the *Intensity* of pressure due to a column of water of the height due to the velocity with which the water meets the floor.

The difficulty was to test this experimentally.

The masonry floor ab may be conceived as resting on a dry vault, in the arch of which, as well as in the floor ab , small holes are drilled, in which spring pressure gauges are fixed, and so placed that their discs, while under pressure, coincide with the surface of the floor. The pressure indicated by each gauge, as read from the vault below, divided by the area of the disc, would give the intensity of the pressure at the centre of the disc. The intensity and distribution of the pressure generally

along any line of discs could in this way be ascertained, and might be represented by a diagram or curve, *see Fig. 17*, in which the ordinates are in proportion to the Intensity of pressure at each disc. The same result might be obtained with one hole and one pressure gauge, provided the jet of falling water could be moved about from place to place in a horizontal direction, and in a definite manner, or, which is the same, the jet might be allowed to remain in one place, and the floor moved into different known positions relatively to the axis of the jet, and an observation made for each position. This was the plan adopted. The floor, if I may so call it, was made of an evenly turned brass plate, 9 inches in diameter, soldered to a tin funnel with a cylindrical spigot 2 inches long and 1 inch in diameter, which fitted into a corresponding faucet in a vertical tin tube, and in the centre of the brass plate was an accurately drilled hole $\frac{1}{8}$ th of an inch in diameter, *see Fig. 18*. The joints were made water-tight by means of short pieces of Indian rubber tubing stretched over the outside.

In the first instance the pressure gauge consisted of a flexible Indian rubber tube fixed at F to the tin pipe DEF, and to the upper end of which was attached a glass tube about 12 inches long; the latter was held in the hand and raised or lowered as the water rose in the glass. The intensity of the pressure of the water against the plate over the hole was indicated by the height to which the water rose in the flexible tube, as seen through the piece of glass tube at the end. The plate and tin funnel to which it was connected were rigidly fixed to an adjustable wooden frame JKT, (*see Fig. 19*), by which the plate could be held steady and at any required height. The first rough experiment* was at a bathing tank, where the surplus water flows through a series of spouts placed about 5 feet above the ground. The arrangement is illustrated by *Fig. 19*.

The plate was properly adjusted under the falling jet, and the water soon began to rise in the pressure tube, and continued to do so until it rose to within 6 to 10 inches of the level of the water in the tank, after which it was sometimes suddenly jerked up several inches above the level of the water in the tank, but it as suddenly fell again, and at first the in-

* My thanks are due to Mr. A. Grant, Executive Engineer, Irrigation Department, who kindly assisted me in carrying out this experiment, and who suggested the use of the short glass tube referred to above.

ference was, that the intensity of the pressure on the plate immediately at and around the hole, was *greater* than that due to the height of fall below the water surface in tank and the plate; but on lowering the glass tube so as to let the water flow out of the pressure tube, which it did with considerable force, depending on the degree to which the mouth was lowered, it was found that large *bubbles of air* passed out along with the water. It was thus seen that the jet was imperfect, and that air got mixed with the water as the latter fell. The indications of the pressure tube could not, therefore, be depended on, as during the sudden rise mentioned above, instead of the pressure being that of a head of water equal to X , it was really (neglecting the weight of the air bubbles) only equal to a column of water of the height $x + y + z$, (*see Fig. 20.*)

It was therefore evident that a jet of water without bubbles of free air was necessary, and this was obtained by means of the barrel arrangement shown in *Plate IV.*, where the jet was formed under a considerable head of water, and by means of properly shaped brass mouth-pieces which effectually prevented the ingress of free air. The barrel rested on three adjustable legs Q, Q, Q . It was placed immediately below a rock over which the water of a ravine was led to the barrel by means of the trough T . The supply of water was regulated by means of two sluices.

In the case of Experiments Nos. 1 and 2, the supply was greater than necessary, and a little surplus water was allowed to flow over the sides of the barrel in this way, maintaining a practically invariable head of water. In the case of Experiment No. 3, the discharge through the 2 inch orifice, with the full head on, was more than the total available supply of water in the ravine, hence the water surface in barrel sank until an equilibrium was established with a head of 26 inches.

The water from the trough was received on a submerged piece of cloth loosely stretched across the mouth of the barrel; this effectually prevented the agitation which would otherwise have been caused by the inflowing water in the case of Experiment No. 3.

In the bottom of the barrel were two orifices, into one of which the perforated cork R , and into the other various sized brass mouth-pieces A fitted. R was connected with the vertical glass tube $H'J'$ by a long flexible Indian rubber tube RR ; the water in the tube $H'J'$ therefore gave the head of water in the barrel.

The jet of water formed by the mouth-piece A was regularly deflected

on all sides by the plate CD, and a portion of the water was forced through the hole B, and in about 20 seconds rose to a certain height in the glass pressure tube HJ.

A scale graduated to inches and sixteenths of an inch with its zero in the plane of the upper surface of the brass plate CD, showed the relative heights of the water in the barrel and in the pressure tube for each position of the plate CD.

The wooden triangular frame was free to move on a horizontal axis MM, while the board to which the plate and the glass tubes were fixed, could be moved up and down in a groove cut in the triangular frame, and made fast in any required position by the thumb-screw P.

A brass micrometer screw O, was fixed to the barrel and to the triangular frame, and so placed that two complete turns of the handle, as indicated by a graduated disc and pointer, caused the plate CD to move in a horizontal direction by one-twentieth of an inch.

Owing to the design of the arrangement not being perfect, the plate CD did not move quite parallel to itself, but followed the course of a tangent plane to a cylinder some 28 inches in diameter, and so, except when the hole B coincided with the axis of the jet AB, the latter was not exactly perpendicular to the plate. But as the range of angular error in the worst case was not more than 2 degrees, the effect of this error on the result was inappreciable. This I proved by actual trial.

The brass mouth-pieces used in Experiments Nos. 1, 2, and 3 (*see Figs. Nos. 28, 25 and 27*) were very accurately turned on the inside to the form shown in B, *Fig. 24*, of Neville's *Hydraulics*, Section VI., page 150, second edition. Hence the co-efficient of discharge for the whole area was very nearly unity, (see page 151 of above work,) and I should say for the portion near the centre of the orifice it was almost exactly unity, so that the velocity of the water in the axis of the jet was almost the theoretical velocity due to the head in the barrel, added to the drop between the barrel and the brass plate CD.

The mouth-piece used in Experiment No. 4, (*Fig. 29*), from its peculiar shape, could not be so accurately finished as the circular mouth-pieces, but it was very well made, and the *vena contracta* curves were symmetrical.

The circular flanges of all the mouth-pieces were of the same diameter, so as to fit the one orifice in the bottom of the barrel. A wide In-

dian rubber band stretched on the flange of the mouth-pieces made a water-tight fit with the bottom of the barrel.

A full size drawing of the mouth-piece used in each experiment, is given.

The results of Experiments Nos. 1 to 4 are illustrated by diagrams (*see Plates VI. and X.*) which show clearly the distribution of the pressure along a vertical plane passing through the axis of the jet. As might be expected, the greatest intensity of pressure coincides with the axis of the jet.

The important point to notice is that *in no case did the intensity of pressure reach that due to a column of water of a height equal to the head of water in the barrel, or, in other words, to that of a height due to the velocity*, but that in some cases it approached this limit to within one-sixteenth of an inch, so that had interfering causes been entirely removed, the surfaces of the water in the two glass tubes would have been on the same level for axial positions of plate.

Experiment No. 5 (*see Plate X.*) was made in imitation of an ordinary canal fall, where AB is the face of the crests or drop wall, BC the floor, and AB, BC, side walls. The head or drop producing velocity was 40 inches throughout, and the adjustable plate AB was moved about in order to ascertain the position giving a maximum head in the pressure tube. The maximum intensity of pressure on the plate was found to be $\frac{3}{4}$ ths of that due to a column of water equal in height to the height of fall or head producing velocity. In practice, with rough straight crest walls the proportion would probably not be greater than $\frac{2}{3}$ ths.

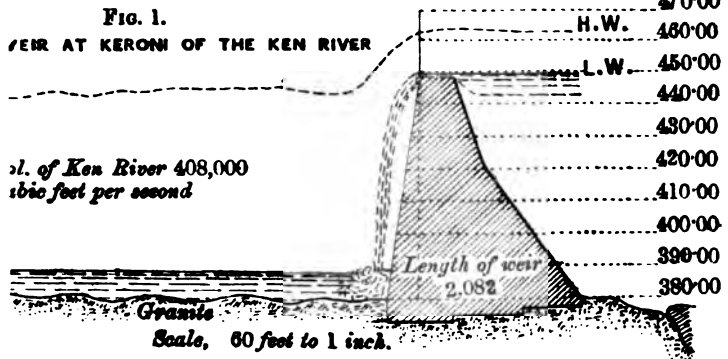
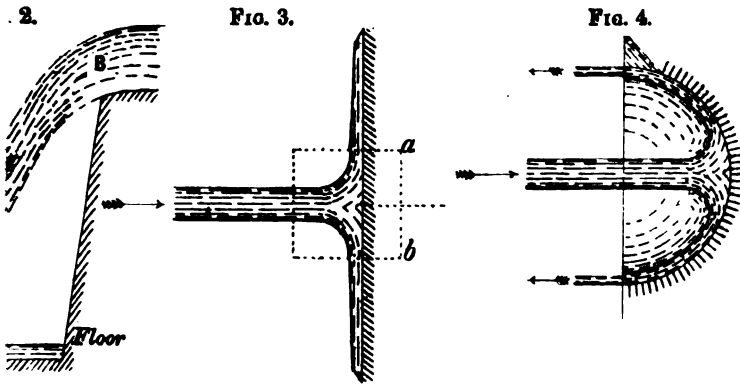
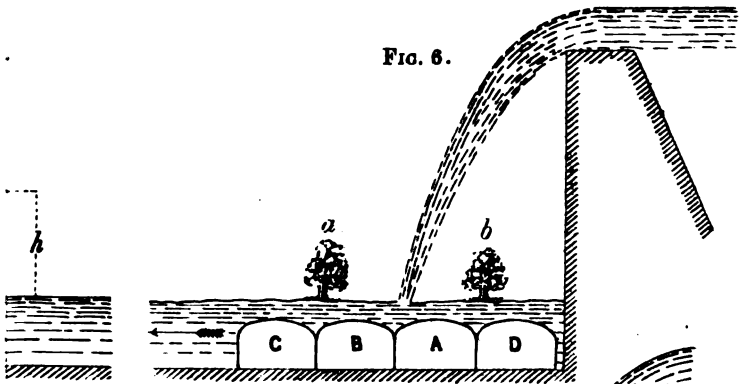
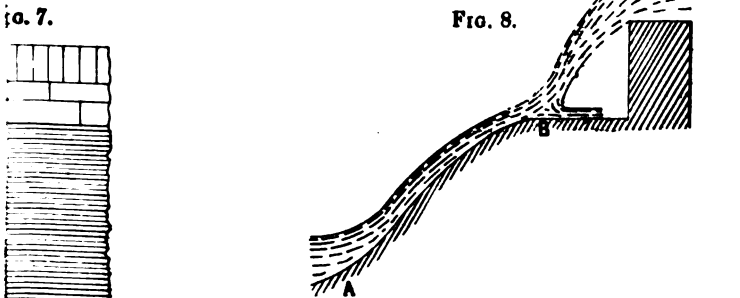
Experiments Nos. 6 and 7 (*see Plate X.*) were made with the view of testing the truth of the last entry in the tabular statement at end of the 4th paragraph of Captain Cunningham's Note (*see page 18*). If the total pressure on a plate of the same sectional area as that of the jet is equal to the weight of a column of water having a base equal in area to the area of the plate, and a height equal to the height due to the velocity, the intensity of pressure, must, in some places be either greater than that of a column of water of a height equal to the height due to the velocity, or if nowhere greater, must be uniform over the whole surface of the plate, and, in amount equal to that due to such a head. But according to Experiments Nos. 6 and 7 neither is the case. The intensity of pressure nowhere exceeded the limit of head due to the velocity, and it varied. Hence it would appear that the total pressure against a plane of the

same sectional area as the jet is *less* than the weight of a column of water of the same sectional area, and of a height equal to the height due to the velocity.

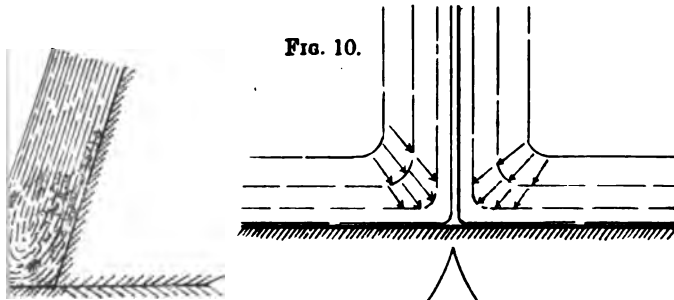
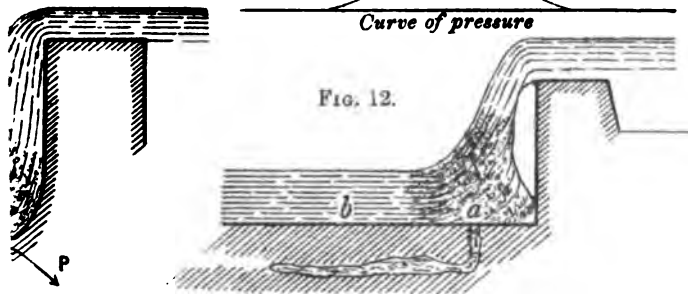
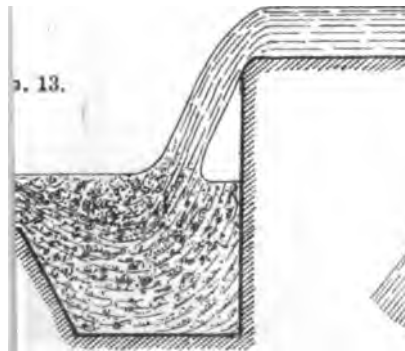
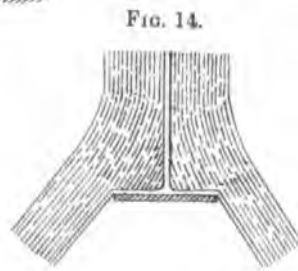
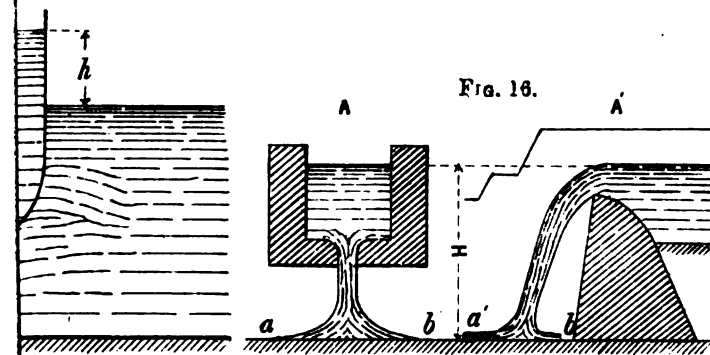
Experiment No. 8 was to determine the distribution of velocity throughout the cross section of a jet one inch in diameter. From the observations noted on *Plate X.*, it would seem that the distribution is uniform throughout the section except at the extreme edge, where the air probably retards the velocity of the outer filaments.

J. S. B.

ON THE ACTION OF FALLING WATER.



ON THE ACTION OF FALLING WATER.



ON THE ACTION OF FALLING WATER.

7.

FIG. 18.

ENLARGED SECTION THROUGH FUNNEL AND PIPE

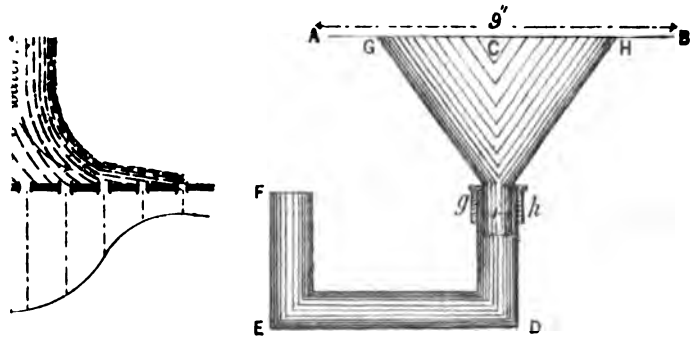


FIG. 19.

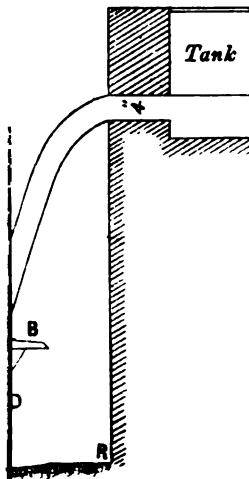
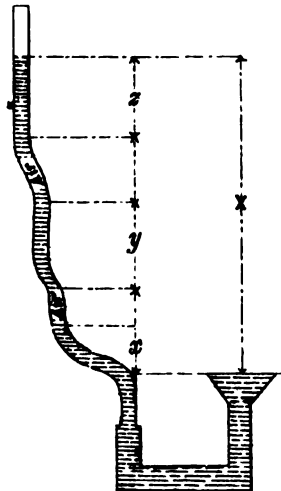
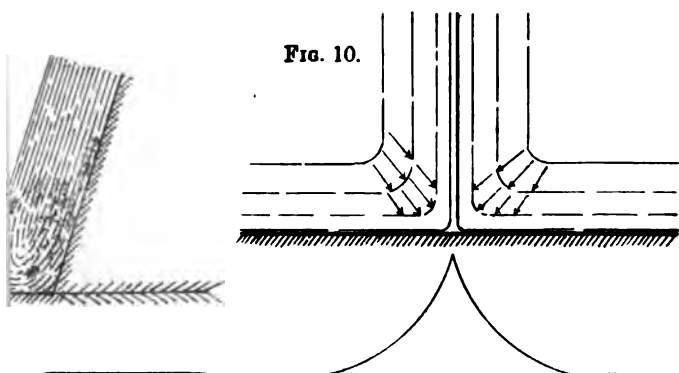
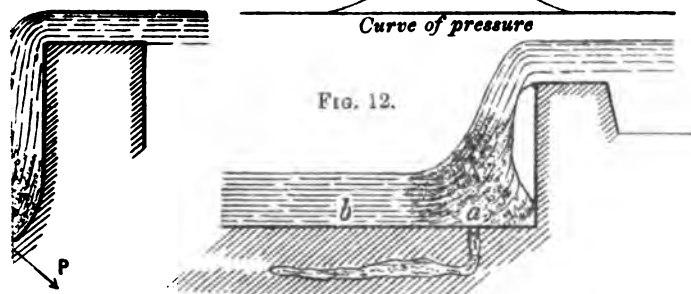
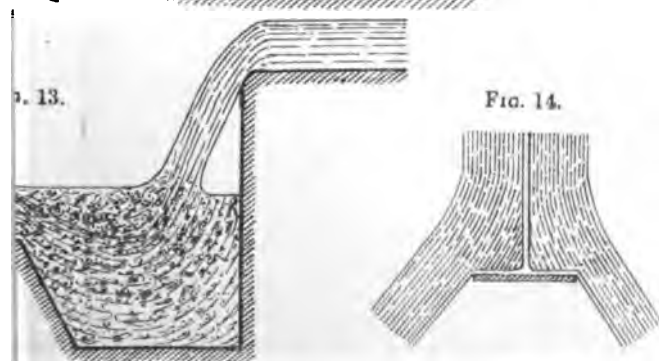
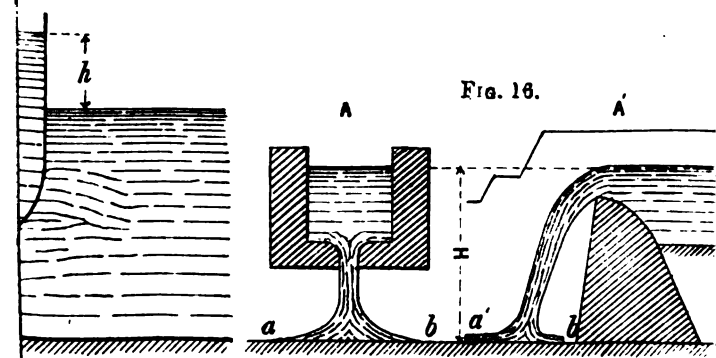


FIG. 20.





ON THE ACTION OF FALLING WATER.



ON THE ACTION OF FALLING WATER.

7.

FIG. 18.

ENLARGED SECTION THROUGH FUNNEL AND

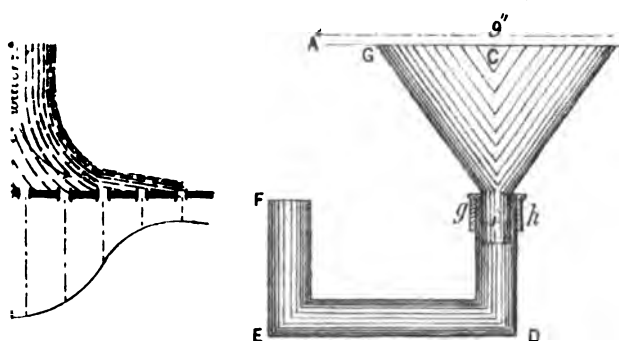


FIG. 19.

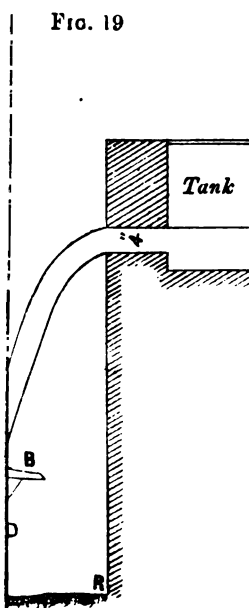
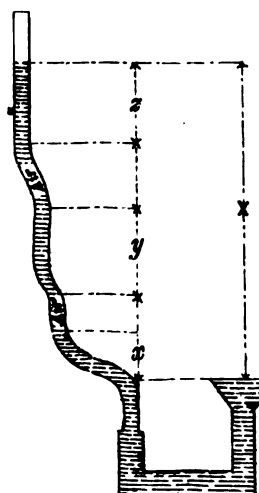
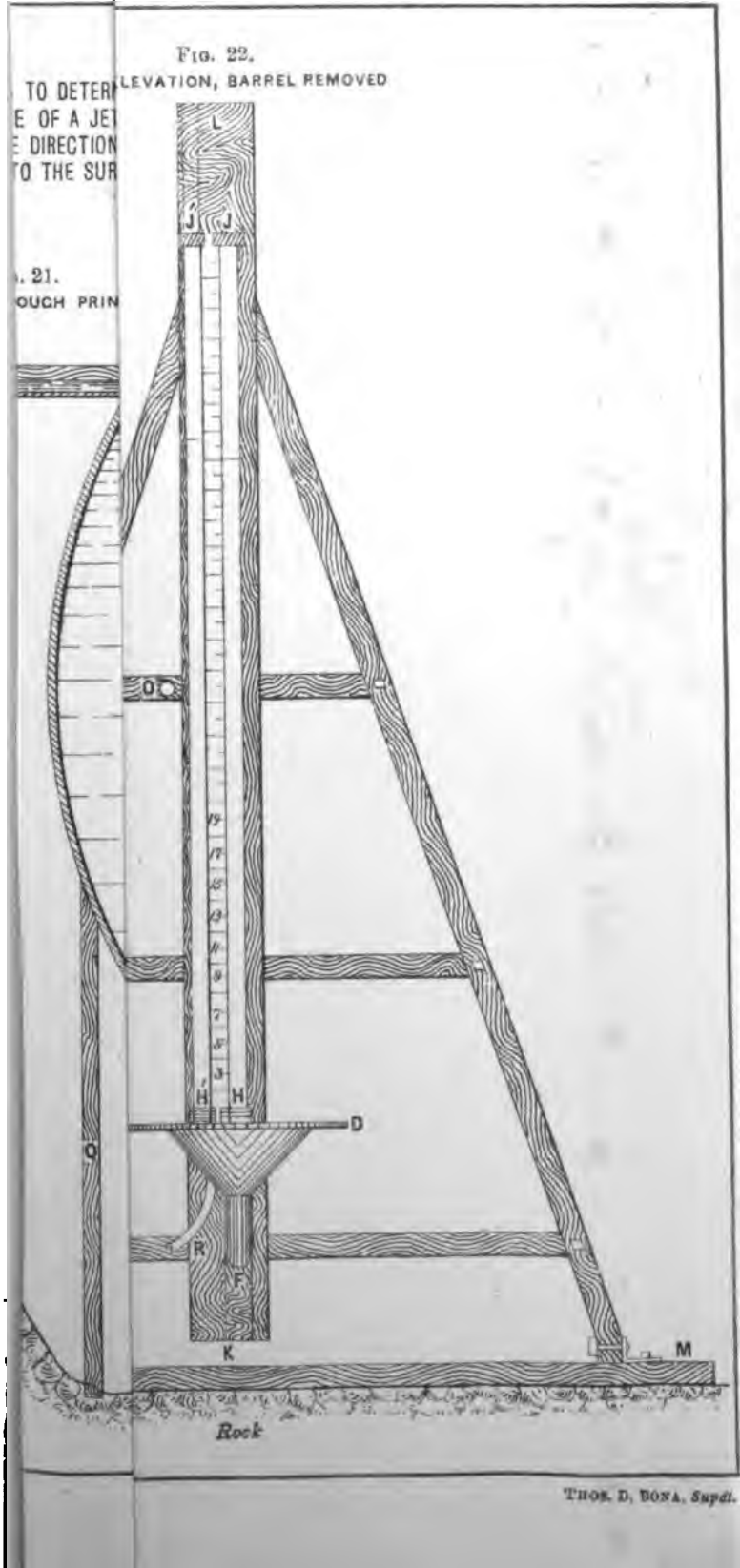


FIG. 20.





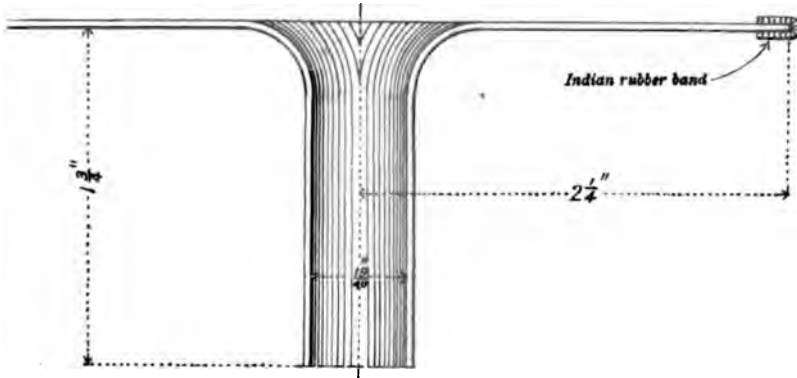
200
100

100
200

100
200

ON THE ACTION OF FALLING WATER.

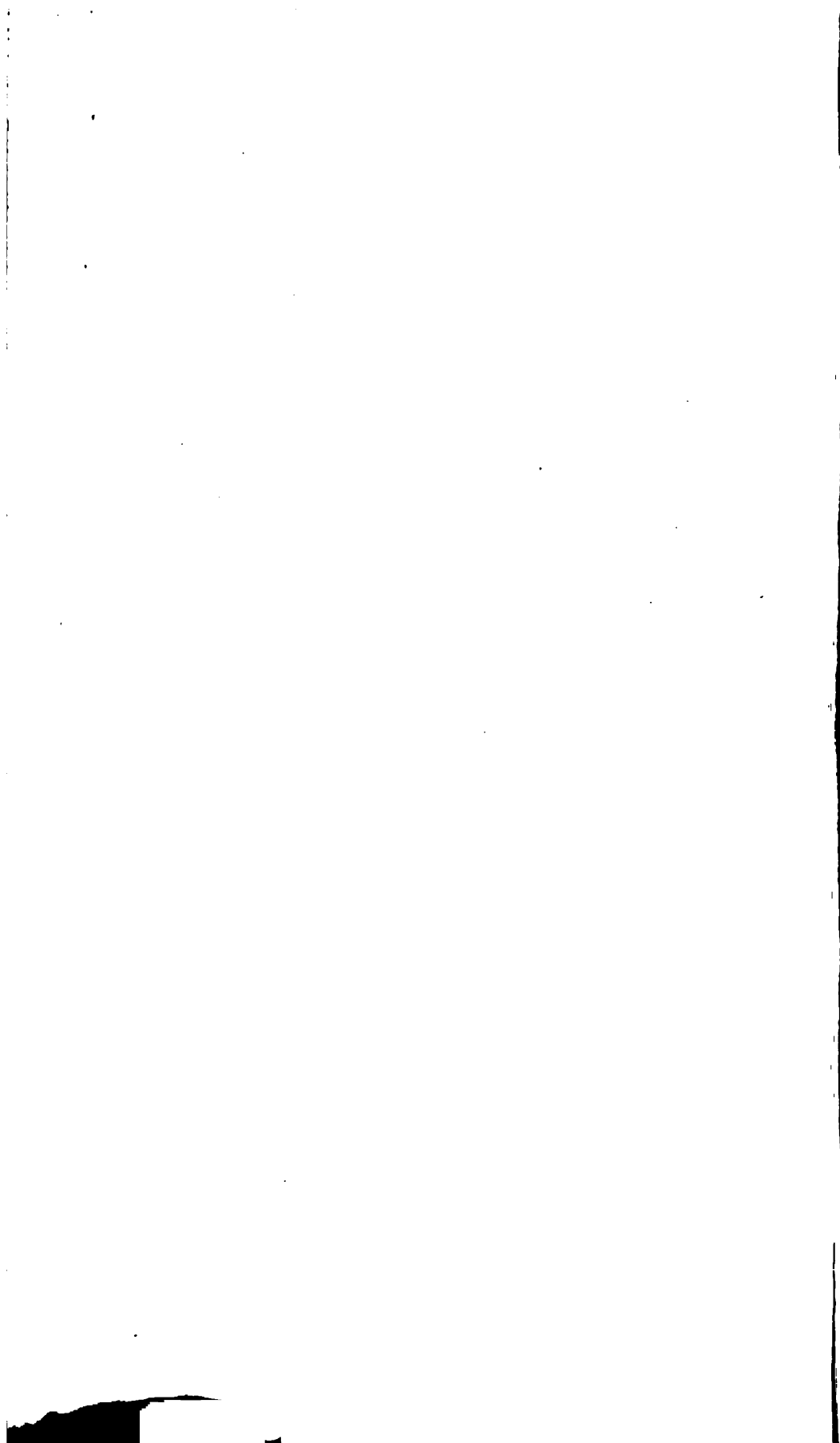
FIG. 23.
FULL SIZE SECTION OF TURNED BRASS MOUTH PIECE



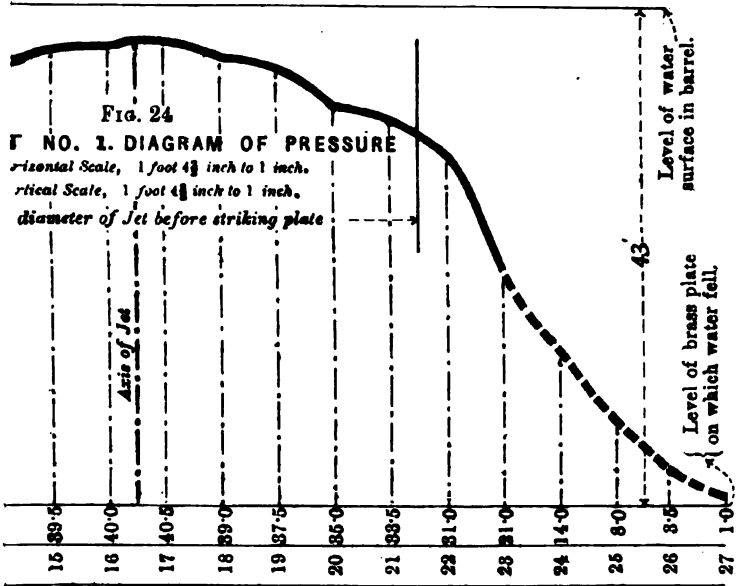
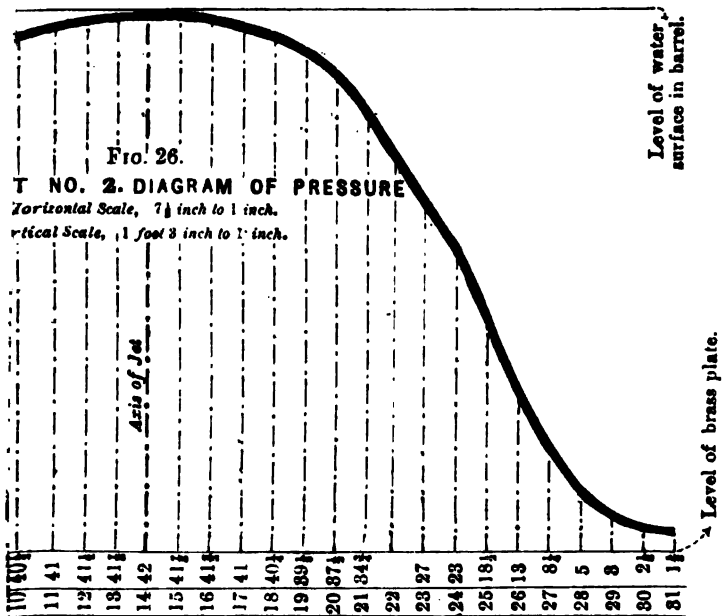
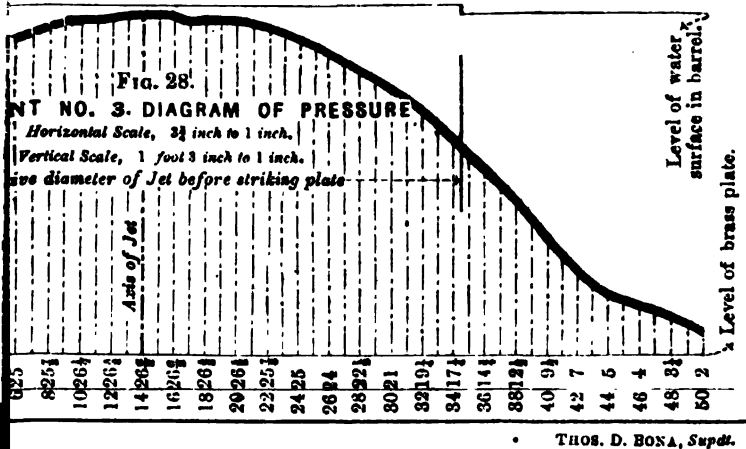
EXPERIMENT No. 1—Figs. 23 & 24.

Experiment on the distribution of the pressure caused by a cylindrical jet of water nearly $\frac{1}{2}$ inch in diameter falling perpendicularly on a horizontal brass plate 9 inches in diameter.

Position of hole relatively to axis of jet.	Head producing velocity.	Head in pressure tube.	Remarks.
	Inches.	Inches.	
4	43	0	
5	"	$\frac{1}{2}$	
6	"	1	
7	"	$3\frac{1}{2}$	
8	"	8	
9	"	14	
10	"	21	
11	"	27	
12	"	..	Not observed.
13	"	37	
14	"	..	Not observed.
15	"	39.5	
16	"	40	
17	"	$40\frac{1}{2}$	Probably axis of jet.
18	"	39	
19	"	$37\frac{1}{2}$	
20	"	35	
21	"	$33\frac{1}{2}$	
22	"	31	
23	"	21	
24	"	..	
25	"	..	
26	"	..	
27	"	..	
28	"	..	
29	"	..	} Not observed.
30	"	..	
31	"	..	
	"	..	



ON OF FALLING WATER.





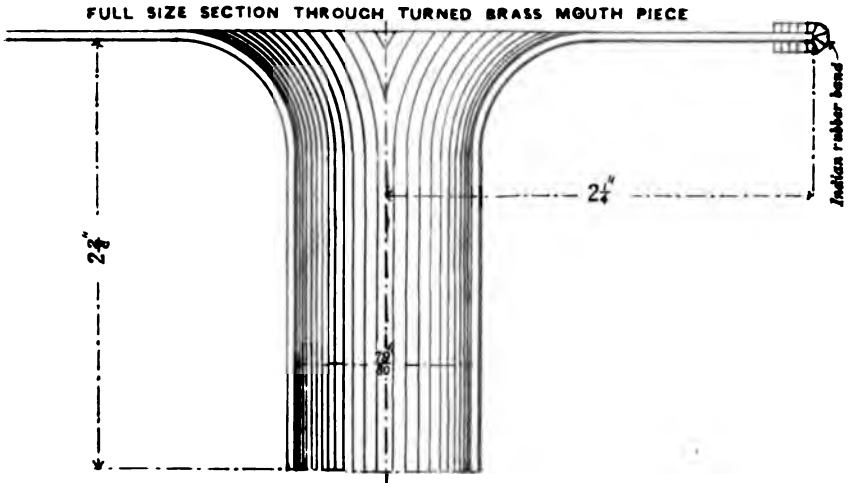
Exp
u

—
valde
plate
to a
—



ON THE ACTION OF FALLING WATER.

FIG. 25.



EXPERIMENT No. 2—Figs. 25 & 26.

Experiment on the distribution of pressure caused by a cylindrical jet of water nearly 1 inch in diameter falling perpendicularly on a horizontal brass plate 9 inches in diameter.

Position of hole in plate relatively to axis of jet.	Head producing velocity	Head in pressure tube.	Remarks.
	Inches.	Inches.	
8	42	37½	
9	42½	39½	
10	..	40½	
11	"	41	
12	"	41½	
13	"	41½	
14	"	42	Probably axis of jet.
15	"	41½	
16	"	41½	
17	"	41	
18	"	40½	
19	"	39½	
20	"	37½	
21	"	34½	
21½	"	33½	
22	"	..	Not observed.
22½	"	29	
23	"	27	
24	42½	23	{ Probably opposite outer surface of jet.
25	"	18½	
26	"	18	
27	"	8½	
28	"	5	
28½	"	3½	
29	"	3	
29½	"	2½	
30	"	2½	
30½	"	1½	
31	42½	1½	
31½	"	1½	
32½	"	1½	
33½	42½	1	

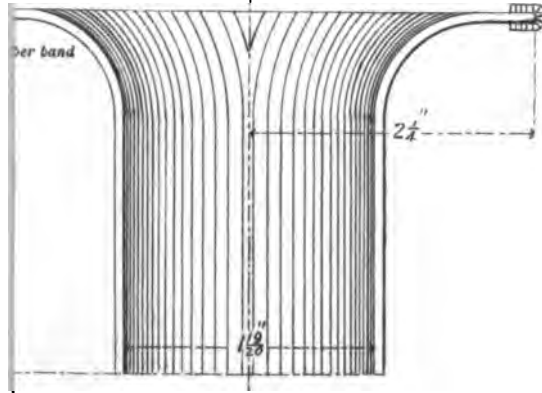
Note on Fig. 27 applies to this experiment.



ON THE ACTION OF FALLING WATER.

FIG. 27.

TWO-THIRDS SIZED SECTION
OF BRASS MOUTH PIECE



EXPERIMENT No. 3—Figs. 27 & 28.

on the distribution of pressure caused by a cylindrical jet
inches in diameter falling perpendicularly on a horizontal
plate of brass 9 inches in diameter.

Head in pressure tube.	Remarks.	Position of hole relatively to axis of jet.	Head producing velocity.	Head in pressure tube.	Remarks.
inches.			Inches.	Inches.	
2	Not observed.	20	27 1/2	26 1/2	Probably axis of jet.
2 1/2		19	27 1/2	26 1/2	
...		18	27 1/2	26 1/2	
3 1/2		17	27 1/2	26 1/2	
3 1/2		16	27 1/2	26 1/2	
4		15	27 1/2	26 1/2	
4 1/2		14 1/2	...	...	
5		14	27 1/2	26 1/2	
6 1/2		13	27 1/2	26 1/2	
7		12	27 1/2	26 1/2	
8	} Max. } Min. } Max. } Min.	11	27 1/2	26 1/2	
10		10	27 1/2	26 1/2	
9		9	27 1/2	26 1/2	
11					
10 1/2	} Not observed. } Probably oppo- } site surface of } jet.				
12 1/2					
13 1/2					
...					
17					
18					
19 1/2					
20 1/2					
21					
21 1/2					
22 1/2					
23 1/2					
24					
24 1/2					
25					
25 1/2					
25 1/2					
26 1/2					

Note.—The numbers indicating posi-
tion in column 1 have reference to a scale
graduated to twentieths of an inch. The
observations were noted at every 1/20th of
an inch horizontally on a vertical plane
passing through the axis of jet.



ON THE ACTION OF FALLING WATER.

FIG. 29.
LONGITUDINAL SECTION
SS MOUTH PIECE

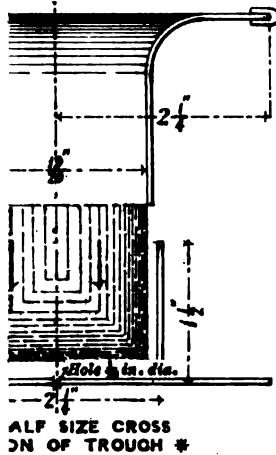
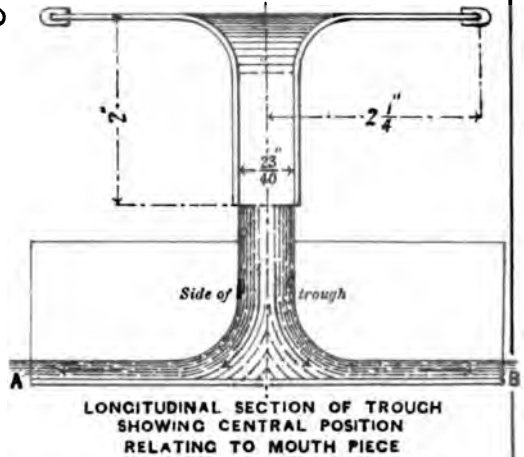


FIG. 29.

FIG. 30.
ONE-HALF SIZE TRANSVERSE SECTION
OF BRASS MOUTH PIECE



EXPERIMENT No. 4—Figs. 29 & 30.

Experiment on the distribution of the pressure caused by a jet of water falling into a trough open at both ends (see sketches above).

Hole to axis	Head producing velocity.	Head in pressure tube.	Remarks.
	Inches.	Inches.	
	40 1/2	2	Not observed.
	41	3	
	"	3 1/2	
	"	5	
	42 1/2	11	
	"	13 1/2	* Note.—The trough was moved from B towards A, and the pressure on hole noted at every twentieth of an inch moved.
	"	15 1/2	
	"	17	
	"	21	
	"	22	
	"	27	
	"	30	
	"	31	
	"	33	
	"	32	
	"	33	Mean—35 was max. " —35 1/2 Steady; probably axis of jet.
	"	34	
	"	35	
	"	35 1/2	
	"	35 1/2	
		34 1/2	Max.
		31	Mean.
		31 1/2	Mean.
		26	} Fluctuating.
		24	
		22	

bon-
di-
t obs-
l on
ach

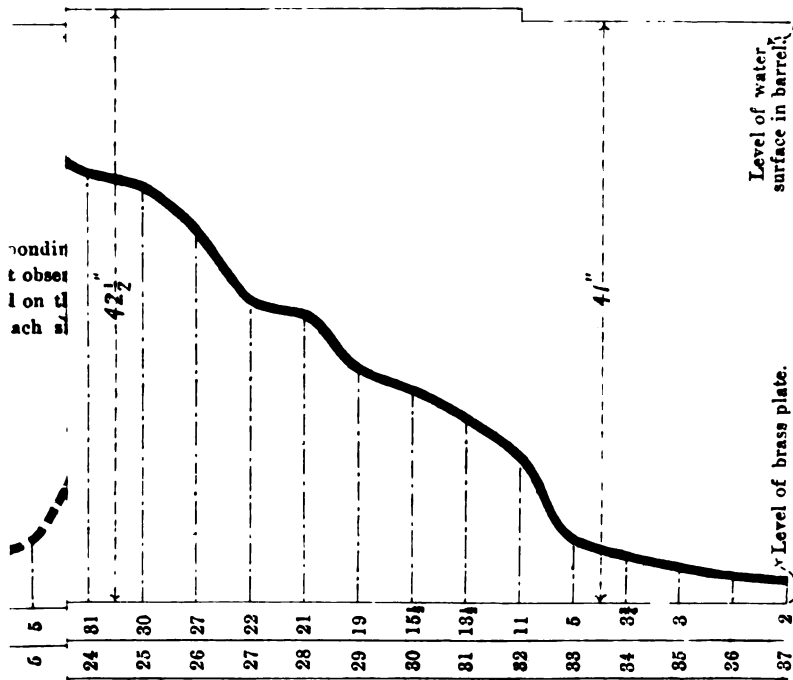
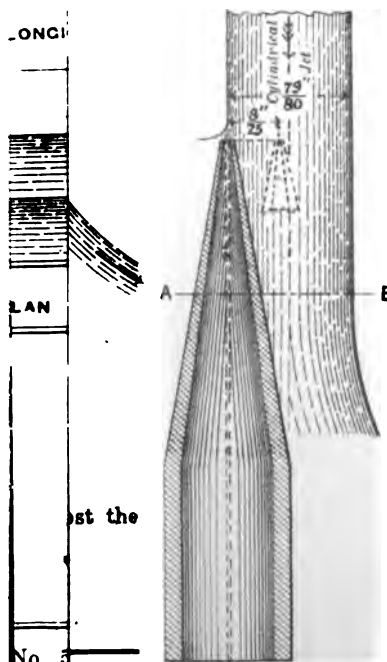
9 | 9

0

[illegible]

2

• • • • •



EXPERIMENT No. 8—Fig. 33.

Position of nozzle as indicated by scale.	Head in barrel.	Head in pressure tube.	REMARKS.
14	37 3/8	34	* The above diagram shows in section the position of nozzle corresponding to No. 14 on scale.
15	"	37 1/2	
16	"	37 1/2	Note.—The nozzle was moved from A towards B by 1/8 of an inch at a time, the axis of nozzle traversing a plane through axis of jet.
17	"	37 1/2	
18	"	37 1/2	
19	"	37 1/2	
20	"	37 1/2	
21	"	37 1/2	† The dotted line shows nozzle in the position corresponding to No. 23 on scale.
22	"	37 1/2	



No. CCCXXIII.

ENQUIRY INTO SUPPLY OF SLEEPERS FOR INDIA.

Seeing that the supply of deodar sleepers was insufficient, and that there was a possibility of the importation of sleepers from England being interfered with, an enquiry was started in July 1878 as to the possibility of using the inferior Indian pines impregnated with some preservative substance. The following extracts from the official correspondence will explain what was done and the result.

The Secretary, Department of Revenue and Commerce, stated that the only plan which commended itself was to utilize the inferior pines, and impregnate them with chloride of zinc or sulphate of copper, as creosote was not readily obtainable in India, and Dr. Warth, Collector of Customs, Mayo Salt Mines, Punjab, was called on to prepare an estimate for the establishment of a factory on one of the North-Western Provinces rivers.

Dr. Warth prepared an estimate, prefaced by a report, in which he described the various methods of impregnation in use on the Continent, and gave a good deal of information as to the time impregnated and natural sleepers respectively lasted. He then described the attempts that had been made in India, but stated that the observations as to the improvement on the sleepers were too short and irregular to allow of any conclusion beyond the general one that the processes all effected some improvement. The concluding paragraph of this portion was as follows :—

The results of the experiments made in India as here stated are not conclusive. Much money has been expended without adequate results, but it does not follow from the numerous failures which have here been

recorded, that if persistent efforts are now made to impregnate timber in India with antiseptic substances, the result will not be favourable. But it is essential that only good and effective methods should be adopted, and that these methods should be employed under competent supervision, and should be continued sufficiently long on a systematic plan, to show in what respect they require alteration and improvement.

He then passed on to Part III., proposed plan of operations, as follows:—

In the north-west Himalaya there are large extents of forests consisting of pines, the wood of which, being less durable than deodar, has not hitherto been extensively exported to the plains. It is now proposed to utilize the wood of one of them, *Pinus longifolia*, for railway sleepers by impregnating it with metallic salts.

The sleepers to be impregnated will chiefly come from two sources—the forests on the Tons and Jumna, and those on the Alaknanda and Bhagirathi, and other feeders of the Ganges. Those from the Tons and Jumna rivers will be either impregnated at Rampur Mandi in Dehra Dun, or will be floated down by the Western Jumna Canal, while those from the Ganges will probably have to be brought down by the Ganges Canal. It will probably be the best plan to set up impregnation apparatus at two places—one for the Tons and Jumna sleepers, and the other for those from the Ganges system. If this is done, it will be possible to establish the apparatus at the places where floating ceases; for the Western Jumna Canal this will either be at Jagádri on the Scinde, Punjab and Delhi Railway, or at Delhi; or it might be possible to establish the apparatus at Rampur Mandi in the Dehra Dun, and from that place to cart the impregnated sleepers to Saharanpur, until the Chakrata Railway is constructed, which will afford an easy means of transit. For the supply from the Ganges, the best locality will probably be at one of the points where the Ganges Canal crosses the Scinde, Punjab and Delhi Railway, or where it crosses the Oudh and Rohilkund line, or at Barota on the Canal near Aligarh.

The area required for each factory will probably be about 10 acres. The present estimate is for duplicate machinery, which may either be set up at one place, or which may be divided and put up in two distinct localities.

It is proposed to use the solutions of chloride of zinc and sulphate of

copper, about 60 per cent. of the sleepers being impregnated with chloride of zinc, and 40 per cent. with sulphate of copper. This will furnish data for determining the relative merits of copper and zinc as preservative substances for sleepers on Indian railways. The plant proposed will be sufficient for the impregnation of 145,000 sleepers annually, on the supposition that the cylinders will be charged once only in 24 hours, and that there will be 250 working days in the year. But, in order to leave sufficient margin for repairs and mishaps, the calculation of the working expenses will be based upon the supposition that there will be an annual outturn of 100,000 sleepers only. It is, however, obvious that, under favourable circumstances, and if the cylinders be charged more than once in 24 hours, the annual outturn may be increased considerably beyond the figure named, and that, in this case, the cost of impregnation per sleeper will be considerably reduced. It should here be mentioned that the present estimate is based throughout on the assumption that only broad gauge sleepers $10' \times 10'' \times 5''$, containing 8.47 cubic feet each, will be impregnated. These data can, however, be made applicable to metre gauge sleepers, 7 of the latter being counted for every 3 broad gauge sleepers.

Sulphate of copper or blue vitriol will probably be imported in wooden casks from England, where its average cost is about £30 a ton. Sulphate of copper contains 36 per cent. of water of crystallization, and 25 per cent. of metallic copper. The chloride of zinc of commerce is a heavy liquid, which probably can be imported in strong casks; it contains 25 per cent. metallic zinc, and it ought to be obtainable, on an average, at the rate of £10 per ton in England. The substances will be mixed with water in wooden tanks, which should be large enough to hold sufficient for four days' consumption.

There will be four cylinders, two of copper for the solution of sulphate of copper, and two of iron for the chloride of zinc. The copper cylinders should have an inner diameter of 5 feet and a length of 31.5 feet. The capacity of one cylinder will therefore be nearly 620 cubic feet, and it will contain a charge of 115 sleepers, the aggregate cubical contents of which amount to 391 cubic feet. The sleepers will be piled on frames of bronze running on low wheels, three of which will go into one cylinder. The estimate provides for 10 such frames, 9 of which will be in constant use at one time.

The two iron cylinders will have an inner diameter of 6 feet and a length of 31.5 feet; each of them will thus have a capacity of 890 cubic feet, and will take in a charge of 175 sleepers, with an aggregate volume of 600 cubic feet. The frames for these cylinders will be made of iron, and will also be 10 in number.

The sleepers having been rolled into the cylinder, and the lid closed, the air is exhausted and a partial vacuum maintained for several hours. (In several factories the pressure is brought down as low as 3 lbs. per square inch.) After this the solution is permitted to enter the exhausted cylinder, the air-pump continuing to play for some time afterwards. When the gauge glasses show the cylinder to be nearly filled with fluid, the air-pump is stopped, the communication with the reservoir is interrupted, and the force-pump set to work, forcing the solution into the wood until a pressure of 120 lbs. is reached. This pressure is kept up by pumping slowly or at intervals for as long as may be found necessary. The force-pump is then stopped, and the communication with the reservoir re-established, so as to allow the remaining solution to run back; the lid of the cylinder is removed, and the impregnated sleepers are taken out, to be replaced by a fresh set, which should be ready piled upon the moveable frames.

By this arrangement it would be possible to impregnate two charges in 24 hours. Indeed, there are some factories where the cylinders are charged 4, or even 6 times, in 24 hours. The present calculation is, however, based upon the assumption that the cylinders will be charged once only in 24 hours, because it seems important that, at first, at least the impregnation should be as complete as possible, and this chiefly depends on the length of time the sleepers are allowed to remain in the cylinder. With one charge only, each copper cylinder will prepare 28,750, and each iron cylinder 43,750, sleepers in a year of 250 working days. Two pairs of cylinders, therefore, as previously stated, will turn out 145,000 sleepers a year. To drive the air-pumps and the force-pumps for four cylinders, a pair of engines of 5-horse power each nominal will be necessary.

The whole plant to be purchased in Europe should be arranged in duplicate, thus affording perfect security against stand-still through repairs. There are to be two steam boilers of 10-horse power each. They are not to be tubular boilers, because these are more liable to get out of

repair, but simple cylindrical boilers with one flue each, the whole to be set in masonry. The chimney is to be 75 feet high above the ground; chimney and foundation to be of solid masonry.

To each of the two steam engines of 5-horse power nominal, already mentioned, will be attached a full set of pumps, viz., an air-pump, a copper solution force-pump, a zinc solution force-pump, and a small feed-pump; each engine and set of pumps being capable of doing alone the whole of the work required from the four cylinders. The work may be distributed between the two engines either by working one at full speed to produce vacuum, and to give the first supply of solution, whilst the other will be worked at slow speed to keep up the vacuum and the supply of fluid, or by allotting the air work to one engine and the fluid work to the other.

Although it is contemplated to begin with chloride of zinc and sulphate of copper, yet it is possible that, simultaneously with the employment of these substances, some sleepers may be impregnated by soaking them in corrosive sublimate. This salt has been employed with great success on several lines in Baden, Würtemberg, Bavaria and other countries in Germany; the solution is not forced into the wood under the pneumatic process, but is in wooden tanks which are filled with sleepers kept down by bolts or heavy weights. Should the establishment of a factory be decided upon, it will probably be advisable to make tanks for this purpose at once before the pneumatic apparatus is set up, so as to commence impregnating as soon as the first timber arrives at the factory. It will in every respect be advisable to test impregnation with this substance in India, but no special provision has been made for it in the present estimate.

Dr. Brandis, Inspector-General of Forests, in a memorandum on the proposal and estimate sums up thus—"There is good ground to believe that it will be possible to deliver annually 200,000 sleepers or a larger quantity of the inferior pines at a cost of Rs. 3-8 a piece all round at the impregnating works"; and he concludes "that the practical question which now calls for decision is whether it is likely there will be a demand for this number."

The estimate followed as Part IV.

For plant, ground, and erection; total Rs. 1,18,972.

Working charges for 100,000 sleepers per annum, for the easy and per-

fect impregnation of which number the plant was designed, came to Rs. 47,527, or on 347,000 cubic feet 2·19 annas per foot, or 7 annas 7 pies per sleeper. The rate in Germany was stated to be 1d. per cubic foot. If 200,000 sleepers could be sold the rate would be reduced.

The papers were then circulated to the various Railways and Governments for report on this question, and the summary of replies received, and the conclusion of the Government, were as below :—

Central Provinces.—No experiments in impregnating pine sleepers with metallic salts had ever been undertaken in the Central Provinces, and that unless the cost of the sleepers from Northern India could be reduced, it would not pay to use them.

Hyderabad.—The cost of carriage of impregnated pine sleepers from the Himalayas would prohibit their use on the Nizam's State Railway.

British Burmah.—The question of establishing the factories in Upper India for impregnating pine sleepers does not affect the province of British Burmah.

Director, Central System.—Suggests that experiments be made on the line between Neemuch and Nasirabad with pine sleepers impregnated with metallic salts, and requests early information as to whether his proposals are accepted.

Director, Western System.—States that if the experiment of establishing a factory on the Ganges prove successful, he would recommend that one be set up for the Punjab lines at Jhelum.

Director, North-Eastern System.—No experiments have been made, and the Railways in his System have no interest in the matter of establishing factories for impregnating pine sleepers with metallic salt, as the cost would exceed that of creosoted sea-borne sleepers.

Mysore.—No experiments for impregnating pine sleepers have been carried out in that Province, nor are any sleepers from the Himalayas likely to be required in Mysore.

Scinde, Punjab and Delhi Railway.—The Railway is practically not interested in the question of wooden sleepers.

North-Western Provinces.—States that it is desirable to try the experiment of establishing factories, by which it is hoped to supply narrow gauge sleepers at about Rs. 1-8 each, but that at present it is impossible to say what the requirements of the Government, North-Western Provinces may be.

Oudh and Rohilkhund Railway.—No impregnated sleepers have ever been used on the line. Timber sleepers are only used at level crossings, and the Company have not hitherto found any difficulty in obtaining unimpregnated teak sleepers in sufficient quantities to meet their moderate requirements.

East Indian and Eastern Bengal Railways.—Neither of the Companies wish to have impregnated pine sleepers from the North-West Himalayas.

Madras.—It does not appear that pine sleepers, impregnated as proposed, can be delivered at Madras at the same cost as creosoted sleepers imported from Europe, unless the price of the latter be increased at least 60 per cent.

Bombay.—It is doubtful whether North-Western Himalaya pine sleepers would ever compare favourably in price or quality with the creosoted pine sleepers in use on the Guaranteed Railways in Bombay.

Home, Revenue and Agricultural Department.—Forwards a memorandum prepared in this office, dated 22nd August, 1879, showing the probable demand for railway sleepers of Himalayan pine impregnated in India, and states that, under the circumstances represented therein, the Government of India in this Department cannot at present guarantee an annual demand for 200,000 such sleepers.

Memo. by the Public Works Department on the demand for Railway sleepers of impregnated Himalayan pine, dated 22nd August, 1879.

The opinions and experiences of the several Railway Administrations in India having now been submitted, the Revenue, Agriculture and Commerce Memorandum No. 1140 F of 18th November 1878, with enclosures, on the subject of establishing factories for the impregnation of Himalayan pine sleepers with metallic salts, may be replied to.

The railways of Lower Bengal, as well as those of Western and Southern India, having their termini at or near the seaports, obtain creosoted fir sleepers from Europe at such a low price, that the cost of carriage of impregnated sleepers from the Himalayas would prove prohibitory.

The Oudh and Rohilkhund Railway is laid throughout with iron sleepers.

Of the Scinde, Punjab and Delhi Railway (total length 553 miles) upwards of half is a pot sleeper road, and the Company's Chief Engineer is of opinion that, should the market keep low, it will be economical eventually to replace the existing wooden sleepers by iron.

The question is thus much narrowed, and resolves itself into one which chiefly concerns the East Indian Railway and the State Railways of Northern India.

The Agent and Chief Engineer, East Indian Railway Company, is of opinion that chir (*pinus longifolia*) unimpregnated is useless for sleepers. Impregnation with creosote was fully tried for some years at Aligarh, but was ultimately abandoned as unprofitable. The process was by some believed to prolong slightly the life of the sleeper, but the porous nature of the chir caused it to absorb so much creosote that the cost was found prohibitive.

Impregnation with metallic salts may also prove too expensive, and it is not likely to materially enhance the value of the wood for sleepers. The Agent in conclusion states that the use of chir for sleepers has long since been discontinued on the East Indian Railway, and he declines to give it a further trial.

As regards the State Railways of Northern India, the Engineer-in-Chief and the Manager, Punjab Northern State Railway, concur in the opinion that an ample supply of first class deodar broad gauge sleepers is, and will continue, to be procurable at Wazirabad, at a cost of Rs. 3-6 each.

On the Indus Valley State Railway (500 miles) impregnated sleepers from the Himalayas could not compete with the cheaper creosoted fir from Europe *viâ* Kurrachee.

When the Rajputana Railway is open through to Bombay, creosoted fir sleepers will be procurable at a price which will preclude the use of impregnated chir from the Himalayas.

The Chief Commissioner, Central Provinces, fears that he will be unable to support the proposed factories in Northern India, as the Forest Department of those Provinces has undertaken to supply teak and sal sleepers at Rs. 3-4 and Rs. 1-12 each respectively, delivered along the lines of railway now under construction.

A. M. B.

No. CCCXXIV.

INTER-OCEANIC CANAL PROJECTS.

[*Vide* Plate.]

By A. G. MENOCAL, Esq., C.E., *Member of the American Society of Civil Engineers.*

Extracted verbatim from Transactions of American Society of Civil Engineers, November 1879.

THE object of the present Paper is to present for discussion before the Society of Civil Engineers a question which is now attracting much public interest through the press of the country, and which deserves the most attentive consideration by the Engineer, on account of its magnitude, the engineering difficulties involved in the solution of the problem, and the great interest the world at large has always shown, and will continue to show, in the execution of the work.

It is evident that the American Isthmus has been sufficiently explored by the United States Surveying Expeditions, and by private parties interested in opening a water passage, between the Atlantic and Pacific Oceans, to enable us to determine the difficulties that would have to be met in the construction of a ship canal at the several places pointed out as presenting favorable indications for execution, and on a careful examination of all the available data, the question seems to have narrowed down to Panama and Nicaragua as the only places where the work can be successfully carried out. It is to the discussion of the most prominent features of these two routes, and their relative advantages and disadvantages that I will confine myself.

Three projects for a canal at Panama have been seriously suggested

and estimated upon, two at the level of the ocean, and one with locks. Of the first two, the one extending from the Bay of Colon to the Bay of Panama has been devised by Lieuts. Wyse and Reclus of the French Navy, and lately advocated by M. de Lesseps, the successful promoter of the Suez Canal; and the other connecting the Bay of San Blas, on the Atlantic, with the Rio Bayano in the Bay of Panama, was first partially surveyed by Messrs. MacDougal and Sweet, in the interest of Mr. Kelly, and subsequently re-examined by Commander Selfridge, United States Navy, in 1871, and Lieut. Wyse, in 1878.

The project for a canal, with locks, *vid Panama*, was carefully studied, and the line actually located by the United States Surveying Expedition, under Commander E. P. Lull, United States Navy, in 1875, of which the writer was the Chief Engineer.

Lieut. Wyse's Plan.

This project was first presented for discussion before the International Canal Congress, assembled at Paris, on the 15th of May of the present year, and is fully described by the author in his report to the President of the "Société du Canal Interoceanique," dated April 4th, 1879. As originally projected it consisted of a thorough cut at the level of the oceans, 73,200 metres (45.5 miles) in length, 20 metres (65.6 feet) wide, and 8.5 metres (27.88 feet) depth of water, with a tunnel 72.20 metres (4.8 miles) long. The river Chagres, as well as the Rio Grande, and their tributaries to the number of 22, are to be received into the canal; the only provision made to ameliorate the effect of such an enormous volume of water is 191,000 cubic metres of excavation, in the beds of the streams at the several points of junction with the canal. The estimated cost of the work, as given by Lieut. Wyse, in his report, is 475,000,000 francs, or \$95,000,000.* This line is not one of actual location, but was traced on a map of the isthmus, between Colon and Panama, constructed from such information as could be obtained from the maps of the railroad and the survey of Mr. Garella, made in 1843 for a canal, with locks, on a location other than that adopted by Lieut. Wyse. The elevations of the ground given in the profile were also obtained, as near as practicable, from the same source of information, and the figures are, therefore, to say the least, a rough representation of the natural conditions.

* Approximately 5 dollars go to £1.

This project was considered impracticable by the Technical Commission of the Paris Congress. The sudden and high floods to which the turbulent river Chagres and its tributaries, are subject in the rainy season, and the disadvantages under which those streams would have to be taken into the canal, on account of the elevation of their beds above the sea, the proposed level of the canal, together with the current that would be produced in the canal by the rise and fall of the tide in the Bay of Panama (the spring tides amounting to 22 feet), would form such impediments to navigation, and so many serious difficulties, and doubtful elements in the execution and permanency of the work, that the plan had either to be modified or abandoned altogether.

A Sub-Committee composed of the following distinguished Engineers, *viz.*, Messrs. Ruelle, Cotard, Couvreux, Favre, de Garay, Laroche, Lavalley and Lepinay were appointed to estimate on the probable cost of the tunnel designed by Lient. Wyse. They reported that, supposing the work free from water, its probable cost would be about 38,500 francs per lineal metre, or \$59,444,000 for the length of tunnel proposed, and with 25 per cent. added for contingencies, \$74,305,000. But if the work had to be done under water, as it was thought would be the case in that portion of the excavation below the level of the sea, then the above estimate would be insufficient, and although the Committee could not, in that event, arrive at the approximate cost, it was of the opinion that the expense would be increased by at least 100,000,000 francs or \$20,000,000.

To meet these objections Lieuts. Wyse and Reclus submitted several plans, more or less feasible, from which the following modifications to the original plan were accepted and estimated upon. A tide lock at the Pacific terminus to keep the surface of the water in the canal at the mean level of the Atlantic; an open cut in place of the tunnel; and new channels to carry to the ocean the waters of the river Chagres, and its tributaries, from Matabin to the sea, independent of the canal, which should be kept entirely free from all surface drainage.

These modifications were considered as an improvement on the first plan; but the Engineers differed widely as to the methods of execution and the practicability of the works proposed, at least, in a commercial sense.

The above-named Engineers, on consultation with the Sub-Committee on locks and profiles, adopted uniform cross-sections and prices per unit

of work for all the projects submitted to the Congress, and the modified project was estimated according to the amount of work computed by Lieut. Wyse at \$208,800,000, exclusive of the indemnification to the Panama railroad.

The Committee remarked in their report that such a sum had been obtained by applying the adopted prices for labor and material to the quantities of work furnished them, increased by the sum of \$8,400,000 named by the Committee on locks, as required, in its estimation for the canalization of the Chagres and its tributaries and necessary accessories, and added that the Committee was of the opinion "that the execution of such works as the long, open cut proposed with a maximum depth of 321 feet above the surface of the water, and the construction of a new channel for the Chagres, the stability of which would not be assured, are subject to so many contingencies and difficulties that it was not possible to arrive at an estimate of their probable cost." The competency of the Engineers hereinbefore named as composing that Committee cannot be doubted; they are men of high established reputation for integrity and professional experience, and their figures and opinions are entitled to full consideration.

I have made careful computations with the object of ascertaining the amount of excavation required for the open cut proposed, and in order to arrive at as close an approximation of the cubical contents as the data at hand would permit, the profile of the route submitted to the Paris Congress by Lieut. Wyse, has been altered by the substitution of the line of actual location of the United States Surveying Expedition, from the Chagres river to the Rio Grande, in lieu of the defective profile of Lieut. Wyse.

It should be stated, however, that the length of the line has not been changed, and that by the profile adopted I have been able to base the computations on an elevation of the ground taken at every hundred feet between those points, and that the dividing ridge is crossed at an elevation of 294.7 feet above mean level of the sea, instead of 321.4 feet as given in Lieut. Wyse's profile. From Colon to the river Chagres, at Matachin, and from the Rio Grande to Panama, no alterations have been made, and the depths of the excavation have been taken from that profile. For the sake of comparison the computations have been made both according to the cross-sections proposed for the Nicaragua and Panama

canals, with locks, and that recommended by the Committee on Locks at the Paris Congress.

The following are the results obtained, *viz.* :—

1st. With the cross-sections adopted for the Nicaragua canal—

Excavation in rock above the level of the sea, ...	61,329,477
" " below " " ...	14,111,806
Total rock, cubic yards, ...	75,441,283
Excavation in earth above the level of the sea, ...	15,904,339
" " below " " ...	7,046,970
Total earth, cubic yards, ...	22,951,309
Grand Total of excavation in earth and rock, cubic yards, ...	98,392,592

Besides this amount, there will be required no less than 1,800,000 cubic yards of rock excavation under water in the Bays of Colon and Panama.

2nd. With the cross-section recommended by the Paris Congress—

Excavation in rock above the level of the sea, ...	38,821,559
" " below " " ...	11,741,022
Total rock, cubic yards, ...	50,562,581
Excavation in earth above the level of the sea, ...	14,694,916
" " below " " ...	8,667,733
Total earth, cubic yards, ...	23,362,649
Grand Total of excavation in rock and earth, ...	73,925,230
Or cubic metres, ...	56,183,174

Which is 10,000,000 cubic metres in excess of the total amount of excavation estimated by Lieut. Wyse for the Paris Congress, on the same cross-section. The amount of rock and earth have been computed according to the geological profile submitted by Lieut. Wyse. It will be observed that the total cube of excavation required with the cross-section proposed by the Paris Congress, is about 25 per cent. less than the amount obtained by adopting the cross-section proposed for the canal by Nicaragua. This is due to the insufficiency of the slopes for rock allowed by the Congress, *viz.*, a vertical cut below and two metres above the water line, and an inclination of one-tenth above that point to the top of the rock. On the Nicaragua route one-half horizontal to one vertical, from the bottom of the canal to 10 feet above the water, and one-fourth horizontal to one vertical above that point to the top of the rock, were

considered necessary to obtain the permanency of the works, and they were so adopted throughout the line. The water prism for the canal in rock proposed for the Nicaragua line is 2,418 square feet; that recommended by the Congress is 2,012 square feet. Nevertheless, it has been repeatedly stated by the friends of the Panama scheme that the dimensions proposed for the Nicaragua route are insufficient for a ship canal, and that to this fact is due the large difference in the estimated cost of the two routes. It is well known to those informed of the variable geological formation of the isthmus, as observed in the digging of wells, excavations for railroads, gold and silver mines, and other works, that vertical cuts and slopes with an inclination of one horizontal to ten vertical are impracticable for the proposed work with a total length of continuous deep cut of $41\frac{1}{2}$ miles, with an extreme depth of 322.5 feet above the bottom of the canal, and a mean depth of 174 feet for a distance of 10 miles.

The amount of excavation herein given is exclusive of what may be found necessary to provide a new channel for the river Chagres and its tributaries from Matachin to the sea, a distance of 28 miles, as recommended by the Congress. No data has been obtained to enable us to arrive at an approximate cost of that work, estimated by the Congress at \$3,400,000. The Engineer may, however, appreciate the magnitude of that undertaking from the fact that the river Chagres, at Matachin, the point of its confluence with the canal, rises about 36 feet in times of flood; that the bed of the river is about 40 feet above the level of the sea, and has an inclination of $4\frac{1}{2}$ feet per mile for a distance of 12 miles above that point. That the channel attains a width, in times of flood, of 1,500 or more feet, a sectional area of 15,000 square feet, a current of 7 miles an hour, and a discharge of about 160,000 cubic feet per second. The inclination of the bed decreases considerably below Matachin, and as its volume is materially swelled by the addition of affluents with large flow, the sectional area of the new channel will have to be increased in proportion. Below Matachin the river, for a distance of 10 miles, runs in a narrow valley confined by high precipitous hills, approaching from both sides. This valley is to be occupied by the canal, the width of which, at the top of excavation, will be about 500 feet. The new channel for the river will, therefore, have to be cut through the high hills on the north, and protected across the narrow valleys by heavy embank-

ments, and, in some cases, masonry walls. Similar difficulties, but on a smaller scale, will have to be met on the south side of the canal in canalizing the river Trinidad and other large streams, tributaries to the Chagres from that side.

The difficulties and contingencies involved in the execution of such works, considering the location, climate, rainfall, &c., cannot be approximately estimated with our present information. Their stability, if ever completed, could not be assured, as they will be constantly menaced with total destruction by the periodical floods of the rivers.

Canals with Locks from Colon to Panama.

In 1875 the Government of the United States, at the request of the Commission appointed by the President to examine the different surveys made for an Inter-Oceanic Canal, and to report as to the line possessing the greatest advantages, sent out an expedition to ascertain the practicability of a canal, with or without locks, across the Isthmus of Panama. In a preliminary examination of the route, it was observed that the high water marks of the river Chagres, in the vicinity of Matachin, disclosed the fact that the river was subject to freshets, which raised its surface to no less than 36 feet above its level in the dry season, which latter was 42 feet above the sea. All idea of a canal without locks, or of utilizing the bed of the river for ship navigation, was therefore abandoned, and attention was directed to the location of a canal with locks that would cross the river at such an elevation as would give a free flow underneath to the highest floods. The summit level of the canal was, on that account, fixed at an elevation of $123\frac{1}{2}$ feet above the mean level of the sea as follows:—

Elevation of highest water mark,	77.70
Rise of arch,	14.05
Thickness of arch,	6.00
Depth of water in the canal,	26.00
<hr/>	
Elevation of summit level, feet,	123.75

The river is proposed to be crossed by means of an aqueduct having 12 spans of 90 feet each, 1,900 feet extreme length, 65 feet wide and 26 feet deep.

The water to supply the canal will have to be obtained from the upper Chagres by means of a feeder $10\frac{1}{2}$ miles long, and involving seven

tunnels with an aggregate length of 13,700 feet, and two siphons of 4,580 feet and 12,000 feet in length, respectively.

Careful gauges of the river Chagres, on the 15th of March, 1875, showed the discharge, at the point the feeder leaves the river, to be 55,900,800 cubic feet per day: an amount of water sufficiently large to supply the canal with 80 lockfulls per day, and to amply provide for evaporation, leakage and filtration. In the month of April of the following year, in passing across the Isthmus, I had occasion to observe that the river was lower, by at least one-third than at the time when the gauges were taken the previous year. Should my estimate be correct, it would evidently show that the supply, to say the least, could not be relied on at all times.

The line was carefully located from the Atlantic to the Pacific, developing an extreme length of $41\frac{1}{2}$ miles. The dividing ridge was crossed at an elevation of 294.7 feet above mean half tide, giving an extreme depth of excavation of 171 feet, plus the depth of water in the canal.

One tide lock is proposed in the Bay of Panama, and 24 lift locks, 12 on each side, of 10.3 feet lift each. The latter were located at those points offering the greatest facilities for construction, with a saving in the excavations. The form and dimensions of the cross-sections for excavation in earth and rock, as well as the prices adopted, were for purposes of comparison exactly the same as had been recommended for the Nicaragua route. The estimated cost, including the necessary improvements in the bays of Colon and Panama, was found, on carefully made computations, to be \$94,511,360. Of this amount, \$18,331,343 are estimated for the construction of 16 culverts and the necessary side drains to dispose of the surface drainage independent of the canal. The disadvantages of this route are: the length of tunneling and siphon required for the feeder, a doubtful supply of water, an aqueduct 1,900 feet long, swamp lands to be traversed by the canal, large mean annual rainfall of 124 inches, and total lack of building material of all kinds fit for the construction of the works recommended. The advantages are: short route from sea to sea, and fair harbours on either side. The railroad, in close proximity to the projected line, is a favorable condition, provided that its owners are willing to give up their franchise for all purposes at the cost of construction or a reasonable consideration, upon which I will not venture an opinion.

The San Blas Route.

This is well known to be the shortest route between the Atlantic and Pacific Oceans; a favorable feature which, with an excellent harbour on the Atlantic side, has always attracted the attention of those interested in the solution of the problem of inter-oceanic canal communication. The line has not been surveyed throughout its length, but from the partial examinations made by Mr. MacDougal, in the interest of Mr. Kelly of New York, in 1864, and by Commander Selfridge in 1871, its total length has been approximately placed at 30 miles, of which from 7 to 10 miles will require tunnelling.

Based on information obtained from these surveys, plans have been prepared for a canal at the level of the sea, the cost of which was estimated by the Paris Congress at \$261,536,595, the tunnel having a section of 1,315 square yards and a length of 8.7 miles.

The main objection to this route is the long tunnel required to pierce the Cordilleras separating the two oceans, having an elevation of from 1,100 to 1,500 feet.

The available data is not sufficient to enable us to determine the probable cost of that work; but it seems to be generally admitted, it will be so large as to exclude it from the number of practicable schemes, at least in a commercial sense. There is no doubt that great difficulties would have to be met in the opening of a tunnel of the dimensions proposed for ship navigation, and it seems to be equally true that almost all the plans suggested to overcome them have been based on assumptions as to the natural conditions. The limited knowledge we have at present of the geological formation of the isthmus has been gained from examinations of surface indications, deep wells, gold and silver mines, the excavations for a few railroads, at far distant points, and the banks and beds of streams. Some of the printed reports on the subject rest on mere superficial observations of only some of those sources of information. For example: a geologist accompanying one of the expeditions follows the *trail* of the surveyors for a distance of 10 or 12 miles, from the coast by the traverses, collects a few specimens of rocks and pebbles from the beds of the streams, takes some notes on the variable character of the soil and rocks cropping out here and there, and returns by the same way to tell us the *fact*, "that the Atlantic slope of the Cordillera in the vicinity of San Blas is composed of the older crystalline rock, such

as granite, syenite and diorite, while that on the Pacific side belongs to the later eruptive period, and its rocks belong to the families of the trachyte and of the basalts, &c., &c." Had he gone but a few miles to the west he would undoubtedly have found at the head waters of the Chagres, deep gulleys or cañons cut in a continuous mass of soft limestone; and not far from there, blocks of trap rock and other varieties of stone, which might have somewhat modified his conclusions. Information so superficial as the above does not seem to "afford a sufficient guarantee that the rock to be met with in piercing a tunnel on the San Blas route will, for the most part, prove to be of a character sufficiently homogeneous and firm to be self-sustaining," as has been assumed in computing the cost of a canal by that route. We have not the data to affirm that the contrary will be the case; but the indications are, I believe, pointing to that conclusion, and the chances are, to say the least, just as much in favor of as against it.

The only way to arrive at the information required for the proper understanding of the subject, and to obtain the data for a fair estimate of cost, would be by sinking a number of shafts to the bottom of the canal on the line of the proposed tunnel. In this manner the character of the rock, and the quantity of water that would flow into the excavation when made, can be approximately determined. Boring with the diamond drill would show the character of the material to be met with, but would not furnish satisfactory information as to filtration. Until that is done the question may be considered as resting on mere *guessing*, in which the opinion of those who have been on the ground and gained information by actual observations should be entitled to most consideration. It is certain that in the construction of an isthmus ship canal at the level of the sea, it will be necessary to contend with water from filtration. This can be drained to the lower levels, while the bottom of the excavation is sufficiently high above the sea to allow the flow by gravitation; but below that level the work will probably have to be done under water.

Pumping by different processes has been suggested as a means to overcome this difficulty, but the experience acquired from a close observation of what takes place in deep mines and in wells dug to a great depth, leads us to believe that such a recourse would be found altogether insufficient, even after dividing the tunnel by bulkheads into a number of small sections. Should these fears prove well founded, it will not be

possible to approximately estimate the ultimate cost of such an undertaking. The Engineers of the first Committee of the Paris Congress, of which Mr. Favre, the eminent Engineer of the St. Gothard tunnel was a member, were of the opinion that such a contingency would increase the cost of the work by at least \$20,000,000. In case the excavations below the level of the sea were carried under water, the men and machinery would have to work from scows, and the dèbris dredged and deposited in dumping scows to be disposed of at the ends of the canal; while all these operations of drilling, blasting, dredging and transporting would have, necessarily, to be done within a width of from 66 to 100 feet, according to the dimensions proposed for the tunnel by different parties. Should it be found, as is apprehended by many, that the material met with is not self-sustaining, and that the tunnel will have to be totally or partially lined with masonry walls resting on the bottom of the canal, the problem will become so complicated that a favorable solution may well be despaired of. That work would have to be done by underpinning from the crown of the arch, carried down to a depth of 28 or more feet below the surface of the water, and for a distance of several miles. By what methods it may be accomplished has not yet been explained. The advocates of a thorough cut are not disposed to admit that these contingencies are likely to be met with, and even deprecate the idea that the chances are just as much in favor of as against them. They will continue to base their estimates on the assumption that the waters from filtration will be no serious obstacle to the prosecution of the work to a depth of 28 or more feet below the level of the sea, as it may be readily disposed of by pumping; that the material will be self-sustaining and sufficiently firm so that no lining of masonry, to speak of, will be needed to secure the stability of the tunnel, and that an inclination of one horizontal to ten vertical will be enough for the slopes of cuts 300 or more feet in depth.

From the above considerations it seems to follow, that the bottom of a canal across any portion of the Isthmus, should be placed sufficiently high above the sea to obtain natural drainage, and that without this condition the work may be considered impracticable on account of its immense cost. This modification involves the necessity of three or more locks on each side, which may not materially change the length of the tunnel, but is sure to considerably reduce its cost by the elimination of unknown quantities in this difficult problem.

The Nicaragua Route.

This line was carefully located from the Atlantic to the Pacific Oceans by the United States Surveying Expedition, under Commanders Hatfield and Lull, United States Navy, during the years 1872 and 1873, and is fully described in the official reports submitted to the Secretary of the Navy in 1873. I was Chief Engineer of these expeditions from the commencement of the surveys to the time the reports were completed, and have subsequently visited the country on three different occasions, and made extensive surveys in connection with this work, and the improvements of the navigation of the river San Juan. I have, in fact, given close attention to the subject for a period of eight years. The estimates of cost were based on the data obtained from a line of actual location. Elevations of the ground were taken every 25, 50 or 100 feet; and sufficient cross-sections, soundings, and gaugings of streams, borings of the ground to the bottom of the canal, or until rock was met with, and such other additional information as to building materials and means of communication as were needed to arrive at a fair valuation of the probable cost were obtained. Nothing was taken for granted, in the formation of the project; therefore, any changes of location introduced hereafter by a more detailed final survey, will, with perhaps one exception, reduce the original estimates.

This exception refers to the enlargement of all curves of less than 5,000 feet radius, objected to by some Engineers, as too abrupt for a ship canal. Distinguished officers of the United States Navy were consulted as to the proper radii to be adopted, and they were of the opinion that 2,200 feet should be the minimum sufficient for the free passage of vessels 400 feet long. The following curves with the radii named were, in consequence, located, viz., 1 of 2,200 feet, 3 of 2,500 feet, 11 of 3,000; 1 of 3,500 and 3 of 4,000 feet; all others have a radius of from 5,000 feet to 10,000 feet.

During the presentation of this route in the session of the 17th May of the Paris Congress, I was asked by M. Voisin-Bey, what, in my opinion, would be the additional expense involved in increasing the radii of the curves. I am reported in the printed proceedings of the Congress, as saying in reply, that \$28,000,000 would be the probable cost demanded by the change. I do not remember what my answer was to that question, but it will be apparent to any one, that I could

not have estimated so comparatively small additional work, at more than one-half the estimated cost of the whole canal. I believe that \$1,800,000 would be a liberal allowance under the most unfavorable conditions. I have referred here to this subject because a writer in the "Bulletin du Canal Interoceanique," a paper published in Paris, in the interests of the Panama scheme, has made a point of that evident typographical or reporter's error, and seems to doubt the accuracy of some of the figures embraced in the estimate of the Nicaragua route, which he could easily verify by computation from the elevations given in the profile of the line, and the cross-section recommended. He will also find in this paper an answer to his statements as to the cubical amount of excavation required for both the Nicaragua and the Panama line.

Lake Nicaragua, the proposed summit level of the canal, is 110 miles long by 30 miles wide, and is situated at $107\frac{63}{100}$ feet above the mean level of the ocean. Several trial lines were surveyed from the lake towards the Pacific, and on careful comparison of their relative merits and elimination, it was decided that those connecting the mouths of the little streams, Lajas and Del Medio, with the port of Brito, presented the greatest advantages on account of their moderate lengths and the comparatively low depressions by which they crossed the dividing ridge.

On a careful location, those lines were found to have an extreme length from the lake to the Pacific of 18.52 miles and 16.33 miles respectively for the Lajas and Del Medio routes. The divide was crossed at an elevation above mean high lake of 43.78 feet by the first, and 134 feet by the second named lines. Considerations of better drainage and shorter distance decided us in favor of the Del Medio route, and the estimates of cost herein submitted are based on the data obtained from the survey of the same. The difference in their locations is comprised between the lake and a place called Las Serdas, where the level of the lake, if continued, would meet the Pacific slope, thence to the Pacific, a distance of 8.33 miles, they form one and the same line. Should it be disclosed by a more detailed survey that the difficulties presented by the Lajas line for a good system of surface drainage can be overcome at a moderate expense, that would certainly be the most advantageous of the two, on account of a small extreme depth of cut through the divide and consequent reduced cube of excavation and cost.

The level of mean high lake is 103.14 feet above high tide at the

port of Brito, an elevation to be overcome by 10 lift locks 400 feet long between gates, 70 feet wide and 10·31 feet lift, located in a distance of 8 miles. The depth proposed for the canal is 26 feet, and the width at the surface of the water 150 feet in earth and 106 feet in rock, with slopes of one-and-a-half horizontal to one vertical for earth, and one-half and one-quarter horizontal to one vertical for rock.

The lake navigation extends from the mouth of the river Del Medio to Porto San Carlos, the head of the river San Juan, a distance of 56·5 miles. The river San Juan is proposed to be made navigable by means of four dams, and short canals and locks to pass them, for a distance of 63·02 miles to the confluence of the river San Carlos, the first large tributary of the San Juan. At this point the canal leaves the river, and is located on its left bank for a distance of 26·90 miles, where it turns to the north, and by an almost straight line reaches Greytown, with a further distance of 15 miles, or a total length of 41·90 miles from the point where it leaves the river at San Carlos. This river it is proposed to divert, so that its discharge into the San Juan shall be below the last dam, and thus keep out of the canal its muddy and silt bearing waters. Ten lift locks of 10·87 feet lift are estimated for this side, three of which are located on the short canals around the dams.

The following table will show the position, and length, height, and other particulars of the dams :—

Location	Distance from lake, in miles	Length of dam, in feet	Height above bottom of river, in feet	Height water is raised in front of dam, in feet
1. Castillo,	37·34	940	21·01	18·87
2. Balas,	44·69	1,196	31·92	22·82
3. Machuca,	50·57	824	33·99	26·84
4. San Carlos, ..	66·81	1,000	30·97	23·87

The first three dams rest on rock foundation and rocky abutments. The last one will rest on a hard and compact gravel bottom, and is intended to be protected by an apron to prevent the undermining effect of the fall. They are designed to be built of concrete, and so constructed that the water in the river will not be raised until the structures are completed in all their parts. This is expected to be accomplished by leaving sluices in the dams sufficiently large to afford a free passage to the river at high water, and to be closed by suitable

gates on the upper sides when the dam is ready to receive the pressure intended. The river will be backed to the lake, the surface of which will be raised from three to four feet, and I estimate that it will take about four months for the river to reach the top of the first dam.

In the meantime the openings in the dams may be closed from the lower side, and the material will have sufficient time to set, before it is brought in contact with the water.

This method of construction will have other advantages in the construction of the canal.

It will permit the dredging and rock excavations under water to be done at a moderate depth, and allow the construction of the short canals and lift locks around the dams, free from the high water of the river.

The total length of the line from Greytown, on the Atlantic, to Brito, on the Pacific, is 181.26 miles, divided as follows:—

Inland Canal.

	Miles
From the mouth of river Del Medio, at the lake, to Brito, ..	16.33
Short canal around Dam No. 1 across the river San Juan, ..	0.78
" " No. 2 " " " ..	1.57
" " No. 3 " " " ..	1.16
From Dam No. 4, below the river San Carlos, to Greytown, ..	41.90
<hr/>	
Total length of canal, ..	61.74
Lake navigation,	56.50
Slack water navigation by the river San Juan,	63.02
<hr/>	
Total miles, ..	181.26

The following is a recapitulation of the estimated cost, viz.:—

Western Division.

From the mouth of the river Del Medio to Brito, 16.33 miles.

	\$
Excavation and embankment,	16,787,566
Ten lift locks, 400 feet by 70 feet, by 10.37 feet lift, ..	3,957,818
One tide lock, 400 feet by 70 feet by 9.00 feet lift, ..	421,306
Drains, grubbing and clearing, &c.,	514,087
<hr/>	
Total for Western Division, ..	21,680,777

Middle Division, or lake navigation, 56.50 miles.

Dredging in mud and gravel and excavation in rock, .. \$ 715,658

Eastern Division, from the Lake to Greytown.

Slack water navigation, 63·02 ; Inland Canal, 45·41 = 108·43 miles.

						\$
Excavation and dredging in the river,	..	..	..	..	..	5,076,030
Short canals around dams,	..	..	..	..	..	1,056,922
Excavation and embankment in canal, from Dam No. 4 to						
Greytown,	..	..	..	..	..	13,889,398
Dams Nos. 1, 2, 8 and 4,	..	..	..	..	..	1,543,526
Lift locks, from 1 to 10, inclusive,	..	..	..	..	..	3,093,160
Drains,	..	..	..	..	..	340,400
Diversion of San Carlos river,	..	..	..	..	..	283,578
Grubbing and clearing (2,379 acres),	..	..	..	..	..	237,900
Total for Eastern Division,	..					25,020,914

Recapitulation.

						\$
Western Division,	..	..	..	..	..	21,680,777
Middle or Lake Division,	..	..	..	..	..	715,658
Eastern Division,	..	..	..	..	..	25,020,914
Harbour of Brito,	..	..	..	..	..	2,337,739
„ Greytown,	..	..	..	..	..	2,822,630
Total,	..					52,577,718
Add 25 per cent. for contingencies,	..					13,144,429
Grand Total,	..					65,722,147

There are about 10,807 cubic yards of rock excavation estimated for, at the west side of the lake, which would have to be blasted and dredged out at a depth of 26 feet below the level of the water in the canal, or 22 feet under water in the lake, at the time of doing the work. This has been estimated for at \$5·00 per cubic yard, which is thought a liberal price, considering that the rock is not a hard solid mass, but boulders and blocks. Colonel Childs' estimate of the same work in 1851, when our present means for doing this kind of work were unknown, was from \$2·50 to \$5·00 per cubic yard. There are also 834,992 cubic yards of rock excavation, and dredging in the river at depths varying from 9 to 14 feet, which has also been estimated for at \$5·00 per cubic yard. Much of this material is loose rock, and the whole would be removed before the river is raised by the dams.

The actual cost of some rock excavation in the river San Juan, at a depth of 6 feet, done recently on a small scale and with scanty means at hand, has been \$2·50 per cubic yard of rock deposited on the banks;

and I have been told by Mr. A. C. Rand of New York, that rock blasting and dredging to a great depth (from 16 to 24 feet) is now being done in the river St. Lawrence, at a cost of less than \$5.00 per cubic yard.

The total amount of excavation, dredging and embankment, exclusive of the harbours estimated upon, may be given as follows:—

Excavation in earth, cubic yards,	82,488,797
" rock,	14,485,477
Dredging in the lake and river,	4,855,935
Embankment,	7,262,629
Excavation in rock under water,	845,719
Total cubic yards,	59,833,557

Deducting from this total cube the embankment which will be constructed with the material proceeding from the excavation, at a small additional expense over that for transportation, we will have 52,570,929 cubic yards as the total amount of excavation and dredging required, or 45,800,000 cubic yards less than the computed volume for the Panama Canal, *a niveau*, with the same slopes and cross-section.

Computing the cubical contents according to the cross-sections proposed for open cut, and a bottom width for the channel in the lake and river of 100 metres (328 feet), as recommended by the Paris Congress, we obtain a cube of earth and rock work of 53,793,982 cubic metres, or 70,663,000 cubic yards, an increase in the total amount of 10,947,998 cubic yards, as shown in the following table:—

Cubical Contents of Excavation in Cubic Yards.

	With Cross- Section of Paris Congress	With Cross- Section for Nicaragua Line	Increase	Decrease
Excavation in earth,	81,535,500	82,488,797	..	898,297
" rock,	10,398,537	14,485,477	..	4,041,940
Dredging in the river and lake, ..	18,209,722	4,855,935	13,353,787	..
Excavation in rock under water, ..	3,380,167	845,719	2,534,448	..
Embankment,	7,262,629	7,262,629	..	..
	70,781,555	59,833,557	15,888,285	4,940,237

This increased amount of excavation is due to the enlargement of the

bottom width of the channel in the lake and river from 80 to 328 feet. The width of 80 feet at the bottom of the channel, with slopes of six horizontal to one vertical, I consider ample for all practical purposes. In fact, a vessel drawing 24 feet would have a channel of 104 feet in width, and for one drawing 20 feet the width would be 152 feet. I cannot see why the channel in the river and lake, if properly marked, should be much wider than in the inland canal, inasmuch as there is no perceptible current in the lake, and that in the river will not exceed one mile per hour after the improvements are completed.

I had occasion to call the attention of the first Sub-Committee of the Technical Commission to the increased cube of dredging and rock excavation under water, as herein given, and suggested that by raising the height of the first dam across the river San Juan one metre (3.28 feet), more than two-thirds of the amount of excavation and dredging could be dispensed with; and also, about 360,000 cubic yards of rock excavation between the lake and the Pacific. This change was not proposed in the original project, because it involved an increase of 3.28 feet in the elevation of the summit level. This would not be justified by the small saving resulting therefrom.

The objections made to this route are: lift locks indispensable to the solution of the problem, length of route, and poor harbours at either end.

A canal without locks, that is, at the level of the ocean, is, no doubt, a great *desideratum*, but its cost, under the most favorable circumstances, would be so great as to place it beyond the possibility of a successful commercial enterprise. The work, if ever done, will be undertaken by private initiative and private capital, and these are not likely to embark in an undertaking which does not promise sure and liberal returns, however beneficial it may be to the world at large, and however great a monument to mark the present age. Under the circumstances, therefore, recourse must be had to locks, which, if properly constructed and sufficiently supplied with water, will be found less objectionable than has been supposed. The objections to locks are: loss of time in passing through, and liability to accidents. With a moderate number of them, properly constructed, the first objection will be found to be of little consideration, and is surely to be compensated for by the smaller tolls charged in proportion to the reduced cost of the work, as compared to other routes.

In pursuance of the system adopted in the design and computation of this project, of not introducing doubtful elements in the whole or any of its parts, the lift of the locks was fixed at 10·87 feet on the Pacific side, and 10·87 feet between the lake and the Atlantic. All of them have been located so that they will rest on rock or stiff dry clay foundations, and there seems to be no good reason why their lift should not be increased to 15 feet, thereby reducing their number to fifteen.

The ground certainly offers all the facilities that could be desired for the change. The Engineers of the Paris Congress fixed the lift at 4 metres (13·12 feet) and the number of locks at seventeen.

General Weitzel, United States Army, is now constructing a lock on the St. Mary Falls Canal of 525 feet between gates, 80 feet wide and 18 feet lift. Through this lock he proposes to pass a ship in 11 minutes, as follows:—

Entering lock,	..	..	..	..	..	1½ minutes.
Closing gates,	..	..	..	..	..	1 "
Filling lock, ..	..	..	..	..	..	6 "
Opening gates,	..	..	..	..	..	1 "
Leaving lock,..	..	..	..	..	..	1½ "
Total,						11 "

The locks I have designed for the Nicaragua Canal would admit passage to a vessel in about 20 minutes, a time which can be much reduced by enlarging the feeding and draining conduits.

I have the authority of Sir John Hawkshaw for stating that from 15 to 20 minutes would be ample time to pass a lock of the dimensions required for the canal, and the latter time has been adopted as a mean.

As to the liability to accident, it seems to me that, if properly constructed, and intelligently worked, no apprehension should be entertained in that respect. Surely no such objections have been met with in the dry docks in universal use, nor in the large canal locks in operation in this country and others that might be named. There are, on the other hand, certain advantages possessed by a canal with locks over one at the level of the sea; for example, all, or the greater portion of the work can be completed before the water is admitted into the canal; any portion of the canal can be partially or entirely drained into the lower levels to allow an examination or facilitate repairs in the channel or locks; a perfect system of drainage, independent of the canal, can be obtained for the adjacent water sheds, and thus prevent floods from doing injury

to the canal. On the Nicaragua line, for instance, all the locks on the Pacific slope, except the lower two, can be drained into the Rio Grande, and similarly some of those on the Atlantic side.

The objection as to the length of the route may be answered by a reference to the statements of distances given before.

It may be seen that the total length of canal navigation is 61.74 miles, and there is no reason why a steamer should not travel in the lake and river with her usual speed at sea.

The estimated time in passing by steamer, from ocean to ocean, is as follows:—

62 miles of canal, at 4 miles an hour,		15½ hours.
68 miles of river navigation, at 6 miles an hour, ..	..	10½ "
56½ miles of lake navigation, at 10 miles an hour, ..	..	5½ "
21 locks, at 20 minutes each,	..	7 "
Total, ..		38½ "

Artificial harbours will have to be constructed at either end of the canal. Plans and estimates have been prepared for the same, and they have received the approval of many distinguished Engineers, and were accepted by the Paris Congress without criticism. It has been determined by careful observations that the sand bank obstructing the entrance to the harbour of Greytown has been formed by the action of the sea striking the sandy beach at an angle. It is proposed to construct a breakwater or jetty, that, acting as a trap, will intercept the sand moving along the coast from east to west. A channel will then be dredged, under the lee of the jetty, to obtain an entrance to the bay, the latter to be sufficiently deepened by dredging to satisfy the demands of traffic.

At Brito, a breakwater, a pier, and dredging will be required to build a harbour large enough to secure a smooth entrance to the canal, and accommodate a number of vessels. With the lake, only 16 miles from the sea by the canal, possessing all the advantages of an excellent internal harbour capable of accommodating all the fleets of the world, the harbour of Brito need not be large.

Building materials of all kind, such as wood, lime, stone, sand, &c., can be obtained in great abundance, either on the line of the canal, or at a convenient distance from it. With the river San Juan, the two lakes and the river Tipitapa, which can be made navigable for vessels drawing

6 or 8 feet at a small expense, an easy and inexpensive line of communication may be established through almost the whole extent of the country by which men, provisions and materials can be transported to any point along the proposed canal, from Greytown to and through the lake, and from the west coast of the latter to the Pacific, a distance of 16 miles, a railroad can be constructed at a small cost, or the present cart roads can be extended and improved so as to answer the purposes intended.

Sufficient data have not been obtained to determine the annual mean rainfall of Nicaragua for a number of years; but, from the observations of Colonel Childs in 1851, those of the Surveying Expeditions in 1872 and 1873, and the records of the College of Granada for the year 1875-1876, we approximately fix at 52 inches on the Pacific slope, and 85 inches on the Atlantic side.

The watershed of Lake Nicaragua is 12,250 square miles, which includes the area of the lake itself, 2,700 square miles. Its outlet, the river San Juan, has a discharge of 12,453 cubic feet per second when at its lowest stage in the month of May, and at high water the discharge is 20,500 cubic feet per second, these being the flow above the point where the canal leaves the bed of the river, to be located on its left bank, and thence to Greytown. Below the point referred to, the flow is considerably increased by the accession of the waters of the rivers San Carlos, Serapiqui, and other tributaries. Below the Serapiqui the flow is about 22,200 and 55,500 cubic feet per second in the dry and rainy seasons respectively.

The Colorado branch of the river San Juan carries to the sea no less than $\frac{2}{3}$ of the volume of the San Juan, leaving but $\frac{1}{3}$ of the flow to discharge into the harbour of Greytown by the lower San Juan. Many have suggested to close the Colorado by a dam, and thus throw the whole volume of the river into the harbour as a means of scouring it out and keeping its entrance open, but this plan has been thought, after much consideration of the subject, to be impracticable and inefficient.

Earthquakes are rather frequent in Nicaragua, but are only slight shocks that never have done any injury to life or property, nor altered in the least the level of the waters in the lakes, rivers, wells, &c. Works built by the Spaniards over one hundred years ago, such as masonry dams across rivers, fortifications, indigo vats, cisterns and the like, are to-day in an excellent state of preservation.

Conclusion.

From the above statements and considerations it seems to follow—

1st. That however desirable a canal at the level of the sea, partaking of the nature of a strait may be, to better satisfy the demands of trade, its execution, either with or without a tunnel, presents so many difficulties and doubtful elements as to place its probable cost out of the range of a successful commercial enterprise.

2nd. That a canal with locks can be so constructed as to satisfy all the requirements of ocean navigation, at a cost within the possibility of a private undertaking, with reasonable expectations of liberal returns and without overtaxing the commerce of the world intended to be benefited thereby.

3rd. That while a canal with locks seems to be practicable, *vid* both Panama and Nicaragua, the latter route possesses greater facilities for the execution of the work at a reduced estimate of cost based on sufficient information to eliminate unknown elements, which might materially so alter the conditions of the project, as to cause painful disappointment to take the place of long deferred hopes and cheering expectations.

And furthermore, that the geographical position of Nicaragua is more favorable to the United States, whose commerce will contribute more than that of any other nation to the business of the canal, while it will afford as great commercial advantages to foreign nations, as other routes more to the south.

Finally, I would state that, while attempting to confine my remarks upon this interesting subject (upon which volumes have been and may yet be written) to as limited a space as possible, I have treated it more at length than was originally intended, and close with the hope that conciseness, if at all attained, has not been at the sacrifice of clearness in the presentation of the points touched upon.

A. G. M.

No. CCCXXV.

MOVEABLE DAMS.

[*Vide* Plates I—VI]

By R. BURTON BUCKLEY, Esq., *Executive Engineer, Bengal.*

THE following systems of constructing moveable dams have been, from time to time, put into practice.

I. In 1818—That of M. Gauthey, called the Barrage à Pontrelles, which was used on the river Seille in France.

II. About 1828—The American system; was adopted on the weir of Neuville on the Marne about 1858.

III. In 1828—That of MM. Thenard Mesnager which was first used in France on the river Isle; this is that system which has been adopted in India on the Mahanuddy, Cossye and other rivers; it has been abandoned in France.

IV. In 1837—That of M. Poirée, called the Barrage à Fermettes, which has been largely adopted in France on the weirs of the Seine, Marne, and the Yonne.

V. In 1841—That of M. Fourneyron, a system proposed to have been fixed under the arches of the Pont-Neuf in Paris, but which does not appear to have been actually constructed.

VI. In 1846—That of M. Desfontaines, adopted on several weirs on the Marne, a system by which the dam is opened and closed by one man regulating sluices communicating with the lower halves of the shutters of the dam.

VII. In 1850—That of M. Chanoine, which is also largely in use on

NOTE.—At the Institution of Civil Engineers on January 20th, Mr. Leveson Francis Vernon Harcourt, M.A., M. Inst. C.E., read a paper on Fixed and Moveable Weirs, and Mr. R. B. Buckley followed with a paper on Moveable Dams in Indian Weirs. The discussion on the papers occupied the 27th January and 3rd February, *vide* Proceedings of Civil Engineers' Institution.—[ED.]

the same rivers, and which has been adopted in India on the tail weir of the Arrah Canal in Bengal.

VIII. In 1853—That known as the Vanne-Déversoir "of M. Poirée," constructed at the weir "De la Monnaie" in the centre of Paris.

IX. In 1868—That of M. Krantz, the Pontoon system. A weir was partly constructed on this principle at Marly on the lower Seine.

X. In 1870—That of M. Girard, a system by which the moveable dam is raised and lowered by means of hydraulic presses. Only one weir on this principle has been constructed, that of the Ile Brulée near Auxerre in France.

XI. In 1870—The system of M. Boulé, which is a modification of that of M. Poirée.

XII. In 1872—That of Mr. Fouracres, which has been adopted on the Sone weir in Bengal.

The system of MM. Thenard Mesnager, as applied on the Mahanuddy, has been described in the Professional Papers on Indian Engineering, No. CCLXII., Vol. VII., First Series, by Mr. Walker. The systems of M. Poirée, M. Chanoine, and M. Desfontaines have been described by Lieutenant (now Major) J. M. Heywood, R.E., in No. I., Vol. VII., of the same Professional Papers.

Since that paper was written, a modification of M. Desfontaine's system has been proposed by M. Cuvinot with some interesting capabilities, but as the system has not been put into use, and as it differs but very slightly from that of M. Desfontaine's, no description of it is here given. The system in use on the Sone weir has been described in the same papers, No. LXVI., Vol. II., Second Series, by Mr. Fouracres.

The object of this paper is to describe briefly the other systems of moveable dams, of which no description has appeared in these papers, and to notice in more detail that of M. Girard, which is a system worthy of much attention.

I. *Plate I., Fig. 1.*—The system of M. Gauthey consisted of a number of openings of about 14 feet 2 inches each, formed by masonry piers built on the floor of the weir. These openings were closed by a number of horizontal needles, or beams of wood, about 6 inches square, placed one above the other up to the level at which it was desired to retain the water above the weir. One end of each needle rested in a vertical groove built into the pier, the other end against a vertical beam of wood 8 inches square,

which was hinged at its lower extremity to the floor of the weir. The top of this vertical beam rose about 15 inches above the top of the pier, and was attached to it by a let-go-gear. When this let-go-gear was released, the beam fell horizontally on the floor, and all the needles were swept away until they were stopped by the small chains which attached each of them to the pier. This system was one which did not long meet with much favour, it was soon superseded by the vertical needle system of M. Poirée.

II. *Plate I., Figs. 2 and 3.*—A moveable dam on the American system was erected at Neuville-an-Pont on the Marne, in a sluice 29 feet 6 inches broad, the floor of which was 3 feet below the summer level of the river. The shutters were in one length of 30 feet 10 inches, the piers being recessed 9 inches at each end, the shutters pressed against the cills formed by these recesses, when they were in the position shown in the section, *Fig. 3*. Both shutters were hinged at their lower ends to the floor. They were therefore capable of oscillating in a vertical arc between a horizontal position on the floor and the inclined position bearing against the cills, in which they are shown in the section, the upper end of the lower shutter was below the underside of the upper shutter, and was fitted with little rollers which diminished the friction between the two shutters when they were lifted.

In the pier, *Fig. 2*, a tunnel was constructed with a sluice at each end, so that it could at any time be placed in communication either with the upper or the lower level of the river. This tunnel was depressed in the centre, so that the aperture which communicated from it to the under side of the shutters was below the bottom of the shutters when they were lying horizontally on the floor. In front of the upper shutter was a small "contre-hausse" about 5 feet 6 inches high, *Fig. 3*, that is, a shutter similar to the upper shutter of the Mahanuddy and Cossye weirs, which was hinged to the floor at its down-stream end, and retained, when vertical, by chains in front of it against the force of the stream. This "contre-hausse" was kept down on the floor by hooks attached to a bar which could be manipulated by a handle attached to the pier.

To close this moveable dam, the "contre-hausse" was first released by the handle on the pier, it raised itself by the force of the stream below it into the vertical position, and closed the sluice entirely up to the level of the crest of the "contre-hausse," as the water was always at a low level;

when this was done the effect of raising the "contre-hausse" was practically to close the sluice entirely. The level of the water above the weir would then begin to rise, and that below the weir to fall. As soon as the difference in the level amounted to about two feet, the sluice connecting the tunnel with the lower river was closed, and that connecting it with the upper river opened. The pressure, due to two feet head, was brought to bear beneath both shutters as they lay on the floor, and raised them up a few inches, the upper edge of the lower shutter bearing upon, and being fairly water-tight against, the back of the upper shutter. As the water continued to rise in the pool above the weir, the difference in level became greater, and the two shutters continued to rise until they bore against the cills in the piers. As soon as the water had risen above the crest of the "contre-hausse," it flowed over and filled the space between the "contre-hausse" and the upper shutter; the "contre-hausse" then fell forward on to the floor, and was fastened down by the bar.

To lower this form of moveable dam, it was only necessary to close the sluice connecting the tunnel with the upper level, and to open the lower one, the water below the shutters would then flow out into the river below, and the shutters would gradually fall into a horizontal position on the floor. It was found that a head of at least two feet was necessary to work this dam. This system offers no facilities for regulating the height of the water above the weir, the shutters cannot be held in any intermediate position.

Concerning this system M. Poirée, whose opinion is entitled to great weight, remarks: There can be nothing more simple in theory, but the system is not without difficulty in practice owing to the enormous friction on the hinges and point of contact of the two shutters.

A modification of this system was proposed by M. Carro in 1870, but it does not appear that any trial was made of it. M. Carro proposed to joint the two shutters together at the top by a longitudinal hinge, and to attach the lower shutter to the floor by a connecting rod about 3 feet long, attached by a hinge to a point on the lower face of the shutter about 2 feet 6 inches from the heel of the shutter. The heels of both shutters were to run along the floor of the weir, as they were lifted or lowered by the water beneath them, on rollers running on rails laid on the floor.

V. *Plute II., Fig. 4.*—The system of M. Fourneyron is very similar to the American system, except that the shutters or gates are hinged verti-

cally and not horizontally. The diagram is a horizontal section through one pier. The gates are opened or closed by the manipulation of the valves in the conduit which brings the pressure either of the upper or the lower river to bear on the chamber which is enclosed by the hinged portions of the gates. Some experiments were made at Chalons in 1846 with this system, but the results were not considered satisfactory.

VIII. *Plate II., Figs. 5, 6 and 7.*—The system of “Vanne-Déversoir,” which was fitted by M. Poirée at the weir “De la Monnaie” on the Seine in the centre of Paris, may be seen there now in operation. The moveable dam consists of four openings of 28 feet 8 inches separated by piers. Each opening is capable of being closed by a “Vanne” of plate iron of the form shown in figures. This dam is only intended to retain a difference of level of about 3 feet when the level of the river is not more than 13 feet above the summer level. The “Vanne” is formed of two diaphragms of plate iron as shown in the section, *Fig. 7*.^{*} The lower diaphragm is a segment of a cylinder, of which the axis is horizontal and across the stream, the upper one is in section across stream (*Fig. 7*) the arc of a circle, the two are joined together by plates and angle irons so that they form a rigid structure, capable, when supported at each end only, of supporting a heavy pressure. The “Vanne” is inserted between the masonry piers, and is attached to them by six iron rods, *Fig. 5*, at each extremity, these rods unite in a casting which is supported on an horizontal pivot 7 inches diameter built into each pier, the centre of the pivot being the axis of the cylinder, of which the lower diaphragm is a segment. The cylindrical portion fits into a similarly shaped cavity in the floor of the sluice, which has at each end a beam of timber which the “Vanne” clears by about quarter of an inch, the upper beam is fixed, but the lower one can be removed if necessary to clear out rubbish, &c. At each end of the “Vanne” a chain is passed round the exterior of the lower diaphragm, and fastened to the up-stream end of it, the other end of the chain is carried up the pier, over a pulley and into a chamber where a counterbalance weight is attached to it.

As the pressure of the water is always normal to the surface of the cylindrical surface of the “Vanne,” and as the weight of the moveable parts are accurately balanced by the counterpoise, the only force to be over-

^{*} I have ventured, Author being in England, to add a small sketch of the Vanne in section as I imagine it works.—[ED.]

come in raising or depressing the "Vanne" against a head of water is the friction on the pivot, and whatever friction there may be between the cylindrical surface and the sand or gravel which may accumulate between the wooden beams and the iron plate. This moveable dam has answered its purpose admirably, the only fault found with it being its cost.

IX. *Plate III.*—The system of M. Krantz was one which M. Krantz introduced to fulfil the following conditions, which he considered essential in a moveable dam. He thought a moveable dam ought—

- (1). To be worked by the force of the river itself without risk to the weir keepers.
- (2). To be entirely under the command of the keepers.
- (3). To regulate automatically any ordinary variations in the level of the water above the weir, and to demand the attention of the weir keepers only at long intervals.
- (4). To be capable of sustaining a severe shock without damage.
- (5). To be easily fitted to the works ordinarily used in the rivers.
- (6). To be sufficiently staunch.
- (7). To be such as to be applicable to much greater falls than those which are ordinarily seen on moveable weirs in practice.

M. Krantz's system was tried for some years at Argenteuil, and experiments on a large scale were made on the weir at Marly below Paris. The apparatus had been removed when the author visited the weir this year, it was said on account of the system not having been successful. M. Poirée wrote a long memorandum discussing, and generally unfavourable to, the system, which has not been permanently adopted anywhere as far as the author has been able to discover.

Plate III. shows a moveable dam designed to retain a head of 9 feet 11 inches. The pontoons C are water-tight and empty. They are made of plate iron in lengths of about 10 feet. Each pontoon has a sufficient displacement to give it a floatation power of about 7,500 lbs. The pontoons are hinged at the down-stream ends to the conduit or framework which is embedded in the foundation of the weir. Each one is in a chamber of its own which is connected with the next one by the opening B.*

This opening B when the shutters are down as in *Fig. 9, Plate III.*, forms with the framework and pontoons a continuous conduit, which at the abutment is connected with the chamber A. This chamber A is

* ? an opening in B.—[ED.]

connected by tunnels with the water both above and below the weir. Valves worked by the wheels V and V' are fitted to these tunnels, so that the water in the chamber A can be kept at the level of the upper water, or at the level of the lower water, or at a level intermediate to these two by a proper regulation of the tunnel valves. It is thus possible to bring any pressure less than that due to the maximum head to bear on the lower surfaces of the pontoons C.

Shutters DE are hinged to the upper end of each pontoon. The axis of rotation is about $1\frac{1}{2}$ inches below the centre of gravity of the shutter, and about $1\frac{7}{8}$ inches below the centre of pressure of the water on the shutter when the water is at the maximum height. Little butterfly valves 3 feet by 2 feet are fixed to the top of each shutter to regulate automatically trifling variations in the level of the river.

The weights of the parts are such that, when the shutters are in the position shown in *Fig. 9*, and the chamber A at the summer level, the moment of the floatation of the pontoon about the hinge at M is somewhat greater than the moment of the weight of the moveable parts about the same point. The shutter then is at the point of rising. If then the chamber A be filled with water, the pressure due to the head in the chamber will be brought upon the lower sides of the pontoon, which will rise up into the position shown in *Fig. 8*. The shutter will, as the pontoon rises, assume the position shown in the same figure.

This system necessitates the construction of a reservoir from which to fill the chamber A when there is no difference in level between the water above and below the weir. When there is sufficient difference of level, the chamber can be filled from the river itself. In order to place the shutters in a position intermediate to those shown in the two figures, M. Krantz proposed to adjust the head in the chamber A to any pressure which might be found requisite. The author believes, however, that it was found in practice that this could not be effected satisfactorily. To lower the shutters it was only necessary to connect the chamber A with the water below the weir, the pressure was then removed from below the pontoons, and they, with the shutters, sunk into the horizontal position.

XI. *Plate IV.*—The system of M. Boulé is a modification of that of M. Poirée. This system has been employed since 1872 at the great weir of the "Port à l'Anglais," the first weir on the Seine above Paris. In

this weir the iron "Fermettes" or folding standards, which are the great feature of the system of M. Poirée, are placed 3 feet 6½ inches from centre to centre, they are 15 feet 7 inches high, 9 feet 10 inches broad at the base, and 3 feet 11½ inches at the top.

These "Fermettes" when erected as shown in the drawings form a service-bridge, across which the weir attendants can pass. Along the top of the "Fermettes," on iron rails which are laid on the top of them, runs a small travelling crane, and a trolley to bear away the shutters, by means of which the weir is closed. During the flood season these "Fermettes" are closed down on the floor below the level of the sill, so that there is no obstacle to the flow of the water. A full description of M. Poirée's system will be found in Major Heywood's Paper above quoted.

M. Boulé's improvement consists in the use of shutters instead of the needles of M. Poirée. In the Port à l'Anglais weir, each opening between the "Fermettes" is closed by three shutters one above the other, each shutter is 4 feet 3 inches high by 3 feet 6½ inches broad. When it is desired to erect the moveable dam, the "Fermettes" are first pulled up into place, the rails are laid across the tops of them, the planks forming the service-bridge are laid down, and the travelling crane is put on to the rails. One by one the lower row of shutters are then placed across the weir, there is but little difficulty in doing this, as the river is, of course, very low when the operation of closing the dam commences. As soon as the first row of shutters are in place, the water above the weir will begin to rise; before it has risen to any considerable height above the first row of shutters, the second row are one by one placed in position above the first ones, and so on. The weir is removed by the opposite process, the first row of shutters being first removed and then the second; the removal of the first row of shutters so far lowers the level of the river that there is hardly more difficulty in lifting the second row than there was in lifting the first.

The "Fermettes" in M. Boulé's system were raised about 12 inches above the highest required level of the water; this was done so that there might be ample time to remove the shutters before the travelling crane became immersed by a rapidly rising flood.

The advantages claimed by this system are—

- (1). That the shutters are made tighter than M. Poirée's needles.

- (2). That it is easier to regulate the river by this system.
- (3). That the discharge can be much more accurately gauged.
- (4). That the water which is discharged over this weir, when it is erect, passes over the top of the shutters, and is therefore available for hydraulic engines of any kind, but in M. Poirée's weir the water escapes largely at a low level through the needles.

It was found that it took, on the average, two to five minutes to remove a shutter on the upper line, five to six minutes on the middle line, and eight to ten minutes on the lower line. This is longer than it takes to work a weir fitted with needles; but M. Boulé considers that the speed of working could be increased if necessary.

X. *Plates V. and VI.*—M. Girard's system of moveable dam is one which demands particular attention, as it is the latest and, in the opinion of the author, the best, although by far the most expensive of all the French systems. It is one which would seem to offer itself as one most suitable, with some modifications, for use in Indian weirs where a workshop was adjacent to the weir to give facilities for keeping in good working order the machinery connected with the system.

The system was proposed by M. Girard in 1869, it was accepted by the authorities connected with the navigation of the Yonne in 1870; a weir on this principle was ordered to be constructed in that year at the Ile Brulée about half a mile below Auxerre on the Yonne. This weir was commenced in 1870 by M. Girard, and was completed in 1873 by M. Callon, M. Girard having been killed in the war of 1870. The author visited the weir this year. It was partly from observations taken during that visit, but chiefly from a pamphlet written by M. Remise, an Engineer of the Pont et Chaussées, that the following particulars were obtained.

The weir and lock were, in their general design, similar to all those on the Seine, Marne, and Yonne as described in Major Heywood's Paper. *Fig. 1, Plate V.* is a general plan of the weir, showing the lock, navigable pass and the "Déversoir" or regulating weir. The floor of the navigable pass is 3 feet 8½ inches below the summer level of the river, and the top of the shutters of the pass are 9 feet 10 inches above the floor, the head retained by the weir is therefore 6 feet 1½ inches, the shutters of the navigable pass are of the ordinary Chanoine type 9 feet 10 inches

high. The masonry crest of the Déversoir or weir is at the summer level, that is 3 feet $8\frac{1}{2}$ inches above the floor of the pass. The tops of the shutters on the crest of the weir are at the same level as the tops of those of the navigable pass. These shutters then retain a head of 6 feet $1\frac{1}{2}$ inches. The navigable pass is 98 feet $4\frac{1}{2}$ inches long, the regulating weir 82 feet.

The shutters of the regulating weir are of wood, they are 11 feet $6\frac{1}{2}$ inches long by 6 feet $5\frac{1}{2}$ inches high. They are hinged on a horizontal axis in cast-iron bearing blocks, which are imbedded in the stone crest of the regulating weir, *Fig. 8, Plate VI.* There are seven shutters on the regulating weir. Below the crest of the weir piers are built immediately opposite the point of junction of the shutters, so that below each shutter there is a bay which can be readily pumped dry to make any necessary repairs when planks have been placed in the grooves provided for the purpose in the piers. On the centre of each shutter a longitudinal bar is fixed, on which the connecting rods which support the shutters are hinged.

Between the piers the lower face of the masonry of the weir slopes at an angle of 30° from the floor. On these sloping faces the hydraulic presses, which work the shutters, are fixed. One hydraulic press is fixed in each bay, that is, there is a press to each shutter. Each is firmly anchored to the weir by two bolts which pass right through the weir walls. The presses are of cast-iron 1 foot $3\frac{3}{4}$ inches external diameter $1\frac{1}{2}$ inches thick. To the head of each piston a cast-iron cross-head is attached, which slides in three cast-iron guides. To this cross-head, at the centre line of the guides, three connecting rods are attached, these hinge on the central rod mentioned above which is fixed to the shutter. (*Figs. 1, 4, and 8, Plate VI.*)

A copper pipe 1 inch diameter connects the lower end of each hydraulic press with the machinery in the pumping-house at the end of the weir. Each press has an entirely distinct pipe, which is carried along the floor in a groove in the masonry. The presses were purposely placed below the level of the water below the weir, so that they might be defended from frost in winter. In the pumping-house is a turbine 3 feet $11\frac{1}{2}$ inches diameter on a vertical axis, which drives a double action pump and an air pump. A reservoir of compressed air (*Fig. 12, Plate VI.*) is fitted in connection both with the air pumps and the water pumps. The pumps

are of the most simple description, and have hardly required any repair since they were erected in 1873. *Fig. 13, Plate VI.* is an elevation, and *Fig. 14, Plate VI.* a plan of the pumping machinery. The vertical axis of the turbine has a horizontal crank (a, a') which works directly on the main shaft which carries the plungers p, p' and the air pump r, r' . The water pumps are marked b, b' . The supply enters through the pipe c , and the pipe d, d' is the discharge pipe which can be connected by a cock either with the cast-iron reservoir (*Fig. 12, Plate VI.*) or directly with the copper pipes leading to the hydraulic presses.

The air pump is a single action one. The piston q' is in the same line and mounted on the same shaft as the pump-plungers, the air enters by the pipe e , the discharge is by the pipe f, f' which communicates with the reservoir. Two ball valves regulate the action of the air pump. By opening the cock g' the air pump is thrown out of work. The small reservoir h, h' is attached to the discharge pipe of the water pumps. This is required when the reservoir is not in use and the pumps are in direct communication with the hydraulic presses.

The water pumps, when the water in the river is clean, suck directly from the river itself, but there is a cistern built into the foundations of the pumping-house which is kept full of clean water, so that the pumps may use it when the river water is foul. The discharge pipes from the hydraulic presses lead into this cistern.

The reservoir of compressed air stands in the pumping room. It is a cast-iron cylinder 24 inches internal diameter, 2 inches thick, and 11 feet 6 inches high. It is in communication with the air and water pumps and also with the pipe d .

The cocks which regulate the connection between the reservoir and the cylinders are shown in *Figs. 10 and 11, Plate VI.* These cocks are placed close by a window of the pumping-house which overlooks the weir, so that the attendant can watch the weir as he regulates its action. The pipe d is connected to the reservoir, the seven cocks mounted on the distribution pipe b communicate with the seven tubes a which are the copper tubes which lead direct to the hydraulic presses.

The discharge from the presses passes through these same cocks and is led by the pipe c to the cistern. The cocks are so constructed that by turning them one-third of a revolution the reservoir is placed in direct communication with the presses; by turning them one-third more the

cock is entirely closed, and by turning them another third of a revolution the presses are placed in communication with the waste pipe *c*.

All the parts of this machinery were tested to a pressure of 500 lbs. on the square inch.

The turbine is started or stopped by lifting or lowering a sluice which communicates with the water above the weir. The entrance to this sluice is protected by a grating. The revolutions of the turbine vary from 30 to 60 per minute, it is capable of developing 12 to 14 horse-power. The pump-plungers, which have an internal diameter of 3 inches, are designed to lift, when the turbine is revolving at its mean velocity, sufficient water to fill the seven hydraulic presses in ten minutes.

The weir is worked in this manner : if the navigable pass and regulating weir are both open, as they are at the end of the flood season, it is, of course, impossible to work the turbine, as there is little or no head of water available. The shutters of the navigable pass are then first erected by the attendants. By the time the water above the weir has risen to the level of the crest of regulating weir, there is generally sufficient head to work the turbine. The pumps can then be put in direct communication with the presses by opening all the regulating cocks, and by closing the communication between the pumps and the reservoir. As the water rises in the river, the pressure resisting the raising of the shutters increases, but the head available for working the turbine increases also. It has been found that there is always sufficient power to close the weir. It takes on the average ten minutes to close the weir in this way.

Generally speaking it is preferable to work the weir by means of the reservoir. If the reservoir is empty, it is first charged by the air pump only, with air at a pressure of 170 lbs. on the inch. This takes the turbine and air pump about an hour. The water pumps are then put to work, and water is pumped into the reservoir until the air is compressed up to about 350 lbs. on the inch. This takes only a few minutes.

When the reservoir has been thus charged, it contains sufficient water and compressed air to lift the entire weir if the head varies from 18 inches to 3 feet 3 inches only. The shutters can be lifted one after another by opening one by one the cocks which communicate with them, or all the seven shutters may be made to rise together by opening all the cocks of the distribution pipe before the cock on the layer pipe *d* communicating

with the reservoir is opened. If this be done, the whole of the seven shutters rise with uniformity in about half a minute.

If the head against the shutters is greater than 3 feet 3 inches, the reservoir does not contain sufficient force to close all the shutters of the weir, it is then necessary to keep the turbine at work while the shutters are being raised to maintain sufficient pressure in the reservoir.

Nothing can be simpler than the work required from the attendant. He has only to see that his machine is kept clean and in good order, and to understand which handle to turn to connect the different parts. He can lift or lower any one of the seven shutters he pleases by simply turning the cock pertaining to that shutter with a handle he could carry in his waistcoat pocket. It is a most interesting sight to see a shutter 11 feet 6 inches long lowered gradually down without the slightest shock or noise of any kind when there is a head of 6 feet 6 inches pressing against it; and to see it raised again against the same head by simply turning a small cock. As the communication with any hydraulic press can be instantly closed or opened by the regulating cocks, it is, of course, easy to retain any shutter in any position that may be requisite, simply by closing the cock when the shutter, either in rising or falling, has reached that point.

It was at first feared that the leakage from the presses and cocks would have caused the shutters to fall gradually as the water escaped from the presses. And it was thought that it might be necessary to place struts behind the shutters to retain them erect. But, after seven years' experience, this has not been found necessary, the leakage is very small indeed, so that it does not effect the shutters to any appreciable degree; indeed the keeper of this weir informed the author that the presses were absolutely tight. There are no fixed supports of any kind, the shutters are always retained erect by the water in the presses.

This system of moveable weir has proved itself a complete success. It has been now at work for seven years, and has hardly ever needed any repair; it was feared at first that the sliding parts would be much damaged by the sand and other matter which would get on them, but this has not found to be the case, chiefly no doubt on account of the arrangement by which the parts exposed to friction are placed on the slope behind the weir. A more serious danger was that of frost, but up to the present no disaster has been caused by it. This last

is a danger which could not interfere with the introduction of this system into India.

XII. Mr. Fouracres' system of shutters, which has been adopted on the Sone weir, has this point of resemblance with M. Girard's system, that the movement of the shutter is controlled by hydraulic pressure; Mr. Fouracres' shutter is lifted in the direction and by the force of the stream, while the hydraulic press controls and checks its motion, but M. Girard's shutter is raised against the stream by hydraulic pressure generated by machinery worked by the force of the stream.

It will readily be admitted that M. Girard's system is by far the most complete, and, for the position in which it is placed, the most effective moveable dam ever erected. Some alteration would have to be introduced if the system were adopted in Indian undersluices. It would be difficult in most Indian weirs to have the presses much below the level of the floor, so the angle at which the presses stand to the floor in the Ile Brulée weir would have to be much decreased in Indian examples, indeed it could probably be best to lay the presses horizontally, and to have small supplementary presses fixed to work vertically beneath the shutters to raise them the first few inches from the floor until the connecting rods were at a sufficient angle to allow the horizontal presses to come into play. The turbines to work the pumping machinery could be worked during the rains by the head which could then always be available through the canal head sluices. In the dry season, if it were ever necessary to work the shutters then, when there might perhaps be little or no head through the canal sluices, the difference of level between the water above and below the weir might be utilized to pump up the reservoir. Indian Engineers would probably object to the machinery connected with this system, and would fear that some accident to the pumping machinery would render, at one blow, the whole apparatus useless. This might certainly occur, and for this reason it would be better to fit up a large hand pump, so that, in the case of the turbine or the pumps becoming choked or damaged, it might be possible to close the shutters by hand. The hydraulic presses themselves and the pipes leading to them, could hardly ever be unfit for use if they were properly attended to during the dry season, when they would easily be got at as they lay on the floor. This indeed has been proved already in India; the hydraulic presses of Mr. Fouracres' shutters have been in use

for five years without mishap in any way due to the presses themselves. It is true that the slides and other working parts would be liable to become choked by sand and damaged by boulders, owing to their being on the floor, and in this respect would be more liable to damage than they are in M. Girard's weir at the Ile Brulée, but the plunger of the press would always be closed inside the cylinder when the shutters were lying on the floor, so it would be protected, and the connecting rods would lie under the protection of the shutter itself. It would be easy also if it were found that any accumulation of deposit choked the space under the shutter, so that the cross-heads had not room to work on the guides, to have an opening beneath the lower edge of the shutter so that as it was lifted a few inches by the vertical presses, a strong scour would be drawn beneath the shutter which would clear away any rubbish that interfered.

The following table shows the cost of the various systems described in this Paper as far as the author has been able to ascertain it from the works of M. Lagrené, M. Remise and M. Debame.

System.	Average height of shutter.	Approximate cost per running foot of the weir.		Approximate cost per superficial foot of shutter.	
		Including foundations.	Moveable parts only.	Including foundations.	Moveable parts only.
	ft. in.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
II. American, ...	8 10	101 0 0	...	11 8 8	...
VI. Desfontaine's	2 10	29 0 0	10 0 0	10 4 2	3 10 5
VII. Chanoine, ...	10 0	39 0 0	10 0 0	8 18 0	1 1 0
Ditto, ...	6 4½	18 0 0	4 17 0	2 16 8	0 15 1
VIII. Vanne of M. Poirée, ...	...	...	21 16 0	...	...
IX. Krantz, ...	9 10	82 10 0	...	8 7 10	...
X. Girard, ...	6 5½	38 2 0	25 8 0	5 18 0	3 18 8
XI. Boulé, ...	13 1½	46 7 0	...	8 10 7	...

The following are the principal books which have been consulted for the information given in this paper :—

Cours de Navigation Interieure, ...	... M. Lagrené.
Barrage Motile Automoteur, ...	... M. Remise.
River Dams or Weirs in France, ...	... Major Heywood.
Memoire Sur le Barrage Motile, ...	... M. Poirée.
Nonvelle Passe Navigable, ...	... } M. Boulé.
Dans le Barrage de Port à l'Anglais,	... }
Manuel de l'Ingénieur, ...	... } M. Debame.
Des Eaux Comme Moyen de Transport,	... }

P.S.—A brief Note to show how an Indian Engineer staying three or four days in Paris on his way through may easily visit some of the most interesting of the weirs on the Seine, Marne and Yonne, may not be out of place here.

Steamers run every few minutes from all parts of Paris to Suresnes on the lower Seine. The steamers take about an hour to get to where there is a weir near Suresnes on M. Poirée's system. At Port Marly, which is about a five mile walk across country from Suresnes, there is another weir on this system. There are also some very large waterworks at Port Marly which are most interesting to inspect. Port Marly may also be reached by train from Paris. From Paris to Renil by ordinary train, and from Renil to Port Marly by tramway drawn by the new fireless locomotive. The weir "De la Monnaie" with M. Poirée's Vanna-Déversoir, is near the Pont-Neuf in the centre of Paris.

Steamers run up the Seine from Paris to Charenton; the weir of the Port à l'Anglais, the largest weir of M. Chanoine's system, is within a mile or so of the place where the steamers stop.

The station of Chelles on the Chemin de Fer de Strasburg is about two miles from the Chocolate Factory of M. Menier at Noisiel-sue-Marne, where there is a weir on the system of M. Desfontaines, also some of the largest turbines in France driven by the fall due to the weir. M. Menier kindly permits visitors to inspect the weir. The weir of Joinville, also on M. Desfontaine's system, is on the Marne, about three miles from Charenton. All these weirs are within 10 or 12 miles of Paris; there is no difficulty whatever in visiting all of them in two days.

The weir of the Ile Brulée on M. Girard's system is about one mile below Auxerre on the Chemin de Fer de Lyon. There are other weirs on M. Poirée's system in the neighbourhood. A day spent at Auxerre by an Engineer on his way to or from Brindisi would be very pleasantly and interestingly spent.

R. B. B.

ELEV

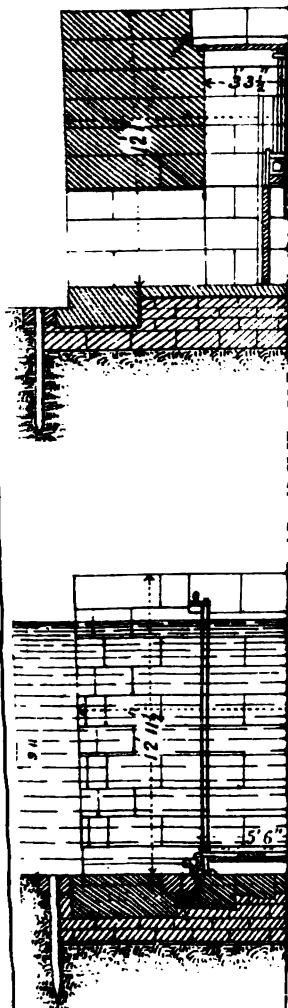


Fig. 7.)

FIG. 6.
PLAN OF THE VANNE

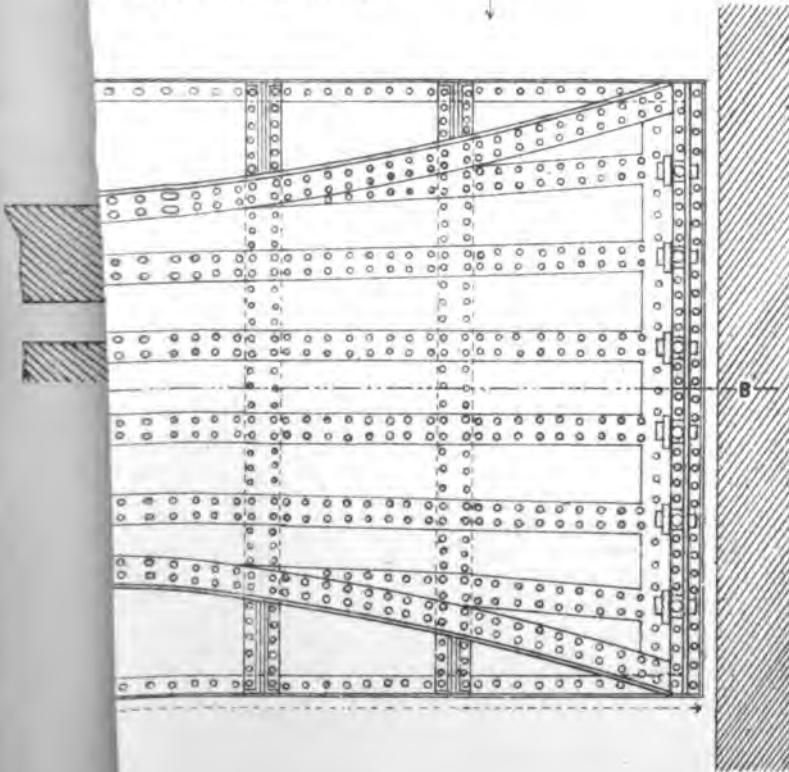
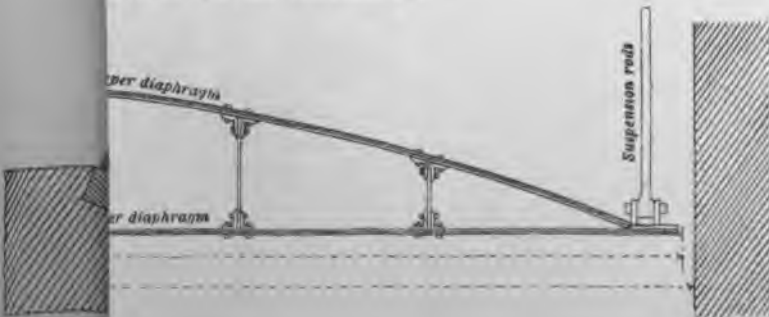


FIG. 7.
VERTICAL SECTION THROUGH AB.



DAMS.

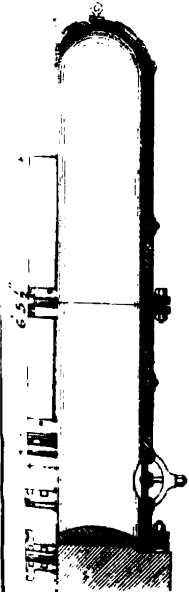
3, 4, 6, 7, 8, 10, 11 and

6 7 8 9 10

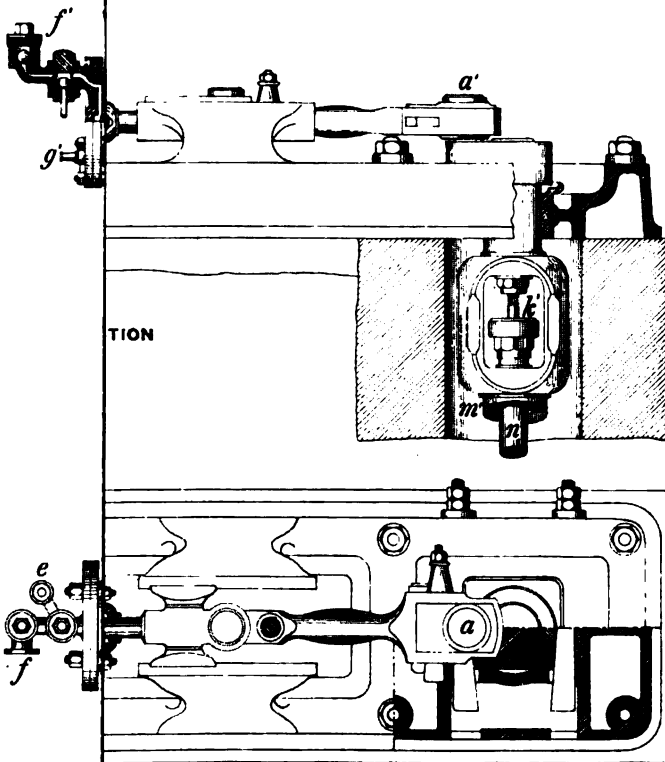
figures 5 and 9.

figures 13 and 14.

FIG. 12.
RESERVOIR



Libo. T.



No. CCCXXVI.

PAPERS ON THE COMPARATIVE WORKING EXPENSES
OF BROAD AND NARROW GAUGE RAILWAYS.

By MR. E. B. CARROLL, *M. Inst. C.E., Locomotive and Carriage Supdt., Bombay, Baroda and Central India Railway*—LIEUT. H. PILKINGTON, R.E., *Acting Depy. Consulting Engineer for Railways*—MR. J. O'CONNELL, *Chief Auditor and Accountant, Bombay, Baroda and Central India Railway Company*—MR. A. M. RENDEL, *Consulting Engineer for State Railways to the Secy. of State for India.*

Comparison of the Rajputana Metre Gauge Railway with the Great Indian Peninsula and Bombay, Baroda and Central India Standard Gauge Railways. By MR. E. B. CARROLL.

Bombay, February, 1879.

IN 1873 the first portion of the Rajputana Railway was opened, and in 1875 the full length, Delhi and Agra to Ajmere. The result of the Railway's working, that is the cost of running its trains, of its maintenance, &c., ought now to be about as good as they are ever likely to be, and to form a perfectly fair basis of comparison with other Railways.

In one important respect—the maintenance of the line and stock—it must cost more rather than less in time to come as they get older.

This does not of course refer to profits, they may and probably will increase as more business is done and more money turned over.

But before comparing working expenses, the much debated question of the relative cost of constructing the Rajputana and other lines may be again referred to on the latest data available.

At the end of the year 1877—the latest date to which analysis of accounts are published—the open mileage of the Rajputana Railway was 396 miles, and the capital outlay £2,538,246, or cost per mile £6,404.

The last half-yearly account, June 1878, gives estimate of further capital expenditure on the 396 miles of Rs. 34,61,646. In these figures Government reduces rupees to pounds at 2 shillings; for comparison, therefore, the additions have to be calculated at the same rate, and will equal £346,164.

When these estimated works are completed, the cost of the Rajputana Railway will be £7,283 per mile.

But the line is unfenced, and for comparison with the Great Indian Peninsula and Bombay, Baroda and Central India Railways, which are fenced, the cost of this must be put down. The lowest rate at which any sort of fencing with gates and lodges could be provided is £200 per mile: this would bring the Rajputana up to £7,483 per mile.

Whether this will be the whole expenditure on line and works it may be impossible to say now, but the probabilities are it will not be. Certainly as regards rolling stock there seems no doubt further additions and large ones will be needed.

The rolling stock at the end of the half-year June 1878 was 70 engines, 236 carriages, and 1,064 waggons: or 0.17 engines per mile, 0.6 carriages, and 2.68 waggons. The proportion on the Bombay, Baroda and Central India, including some additions intended, is 0.2 engines, 0.8 carriages, and 6.0 waggons, and on the Great Indian Peninsula, 0.33 engines, 1.03 carriages, and 6.2 waggons.

The metre gauge stock only carries about half the number of passengers or weight of goods, and the engines are in like proportion. Allowing for this it is clearly much under-provided. An expenditure of only £204,732 (with the fencing) will bring the cost of the Rajputana up to £8,000 per mile: that sum will easily disappear in providing a proper proportion of stock, so it may be safely reckoned on that the Rajputana Railway will cost £8,000 per mile or over. And be it remembered that its cost is already estimated up to £7,283, there is no conjecture about this latter figure.

The above is without counting that when the connection is made between the Rajputana and Bombay, Baroda and Central India, and through traffic established, further increases will be necessary to bring the metre gauge up to the capacity required by the broad gauge lines, with which it connects, and that probably some of it must be laid with a double line to do so.

The early lines in India certainly cost a great deal more than £8,000 per mile; but the cause of this was that they were pioneer lines, on which everything had to be learned and experience bought at a high price. But advocates of the narrow gauge have been disingenuous enough to ascribe the high cost to the gauge—that is to say, because the rails are 66 inches apart instead of 39½ the lines cost £16,000 instead of £8,000.

The statement was always too absurd to require to be refuted, but the question is now fortunately beyond the region of dispute or conjecture, as recent years have seen the completion of some broad gauge lines at very different rates of cost.

The Oudh and Rohilkund has cost £9,733 per mile, the Wadhwan extension of the Bombay, Baroda and Central India £7,200, the Dákor extension £4,000 for the line, or about £5,700 with proportion for stock, workshops, offices, &c.

The Oudh line, indeed, belongs partly to the category of pioneer lines, as only part of it was made since we have been able to get at lower rates of construction, and the whole could now no doubt be built for less.

The Dákor line, it should be stated, is on a very easy country and under favourable conditions, but, on the other hand, it has a full size permanent way with 60 lb. rail.

The Wadhwan line, though on a country easier than the average of the Rajputana Railway, does not owe such a great deal to that, and has a first class heavy permanent way with 60 lb. rail, is fenced throughout: the Rajputana has only 36 and 40 lb. rails and not fenced.

In spite, then, of the Rajputana being metre gauge with light rails, we find its cost creeping up to a higher figure than the Wadhwan line, with standard gauge and heavy permanent way. Much has to be allowed, no doubt, for the fact now at length discovered by its constructors that it must be one of the trunk lines of India, and provided accordingly.

But if this is the cause of its higher and increasing cost, as doubtless it is, there is no escape from the dilemma that a palpable error has been committed in the selection of the metre gauge for this trunk line.

The net result, it appears, then, will be that this disjunctive system of railways, which is being placed between Bombay and the Punjab, will not cost the country a rupee less than if the standard gauge of 5-6 had been carried through.

And what does the country get? A railway communication which,

as the following figures show, has scarcely one-fourth the possible capacity of the broad gauge, will always be dearer to work, can never carry either goods or passengers so cheaply or so quickly, and has a break of gauge at both ends.

Coming now to the comparative working expenses—the cost at which the two classes of railways can convey freight, which is perhaps the most important matter to the public, as affecting their permanent interests—it should be remarked that figures of working cost are very variable according to the circumstances of the railways, and require to be carefully scrutinized and brought down to general averages to have their bearing fully realized.

Taking first the maintenance of line, the Rajputana at a glance appears favourably costing Rs. 587·88 per mile against Rs. 717·11 for the Great Indian Peninsula, and Rs. 1,111·38 for the Bombay, Baroda and Central India, but averaging the maintenance charges over the work done upon each line, the results are very different; the Rajputana costs Rs. 3·83 per each 1,000 tons taken over a mile of line, the Great Indian Peninsula costs Rs. 0·877, the Bombay, Baroda and Central India Rs. 2·54. The Great Indian Peninsula is less than a rupee, the Bombay, Baroda and Central India $2\frac{1}{2}$ rupees, and the Rajputana nearly 4 rupees.

Of course much in these figures depends on the tonnage passing over the line, but, on the other hand, the Great Indian Peninsula and Bombay, Baroda and Central India are incurring large outlay in renewal, especially the Bombay, Baroda and Central India on its bridges, while the metre gauge line is nearly new. These results point to no advantage, but much the contrary in its maintenance.

On this question the Manager of the line remarks that the “rails require to have fish joints substituted for clip joints,” and “that it seems doubtful the sleepers will last very long owing to frequent re-spiking.” “Excessive wear from frequent packing up necessitated by the short sleepers and overhanging stock is also likely to have a prejudicial effect on the life of the sleepers.”

This is no more than competent engineers long ago predicted would be the result of narrowing the way and attempting to carry disproportioned vehicles upon it.

Next as regards locomotive power, taking the most important items, the Rajputana costs for driving the engines 3.38 annas per each train mile, the Great Indian Peninsula 2.57, and the Bombay, Baroda and Central India 2.05. Considering that a metre gauge locomotive is a small affair, and as some figures to follow will show does only one-fourth the duty of a broad gauge locomotive, this cost of driving one-third more for the small engine and train is not promising, and no doubt partly arises from slower speeds and longer time taken to do the distances.

The comparison is still more unfavourable, however, when reduced to the average cost of hauling 1,000 tons one mile, the Rajputana being Rs. 1.45, the Great Indian Peninsula 0.64, the Bombay, Baroda and Central India 0.42. The Bombay, Baroda and Central India less than half a rupee, the Great Indian Peninsula a little over a half, and the Rajputana nearly one and a half.

Then in coal and other fuel, the Rajputana costs 5.74 annas per train mile, the Great Indian Peninsula 5.85, the Bombay, Baroda and Central India 5.88. Or per 1,000 ton miles, Rajputana Rs. 2.46, Great Indian Peninsula Rs. 1.45, Bombay, Baroda and Central India Rs. 1.19. Similarly to the driving this is a very unsatisfactory result, the metre gauge small engine and train costs almost as much for fuel per mile as the large broad gauge engine and train, and per 1,000 ton miles coal on the metre gauge cost nearly double as much as on the broad gauge.

A certain credit must be allowed to Rajputana for dearer coal: it cost Rs. 20 per ton, the cost on Bombay, Baroda and Central India is Rs. 18 to 19 per ton, and the Great Indian Peninsula is lower than either owing to partial use of native coal. Deducting for this so as to make the comparison perfectly fair, the figures would stand, Rajputana per 1,000 ton miles Rs. 1.845, Bombay, Baroda and Central India Rs. 1.19.

Passing the other detail items and taking the total, the Rajputana costs per train mile for locomotive power 13.59 annas, the Great Indian Peninsula 12.09 annas, the Bombay, Baroda and Central India 12.74 annas, or per 1,000 ton mile, Rajputana 5.88 rupees, Great Indian Peninsula 3.01 rupees, Bombay, Baroda and Central India 2.58 rupees. In other words, it costs the metre gauge nearly 6 rupees to do the work which is done on the Great Indian Peninsula for 3 rupees and the Bombay, Baroda and Central India for about 2½.

Next the carriage and waggon expenses; in this the Rajputana is com-

paratively favourable owing to lower expenditure in repairs of carriage and waggons. This of course is to be expected, none of the stock is more than 6 years' old, while that on the Great Indian Peninsula and Bombay, Baroda and Central India require large annual replacements and heavy repairs. For this reason, and the year 1877 being the famine year, the Great Indian Peninsula is unusually high, large expenditure having been incurred on renewals. The figures are per train mile, Rajputana 2·80 annas, Great Indian Peninsula 4·65 annas, Bombay, Baroda and Central India 3·03 annas, and per 1,000 vehicle miles, Rajputana 7·82 rupees, Great Indian Peninsula 14·21 rupees, Bombay, Baroda and Central India 7·41 rupees. In the latter form of average the Bombay, Baroda and Central India is a little lower than the Rajputana, though much of its stock is 15 to 20 years old, and none of the Rajputana more than 6 years, and though each vehicle represents twice the value, and each mile three to four times the work of those on the metre gauge.

On the matter of locomotive and carriage and waggon charges the Manager of the Rajputana Railway says—"The high cost of working this department has been for some time under investigation and comparison with the Oudh and Rohilkund Railway, Locomotive Department. Reductions will, if possible, be made, but do not appear possible or probable to any large extent, for what may be saved by the economies which experience may show to be practicable on the one hand, will mostly be met by the inevitable necessity of reconstruction for the up-keep of the rolling stock when it gets older. This remark applies equally to the permanent way."

Elsewhere the Manager says—"The waggons have been found too weak in the underframes, and vertical cross-bracing is now being put on to prevent the whipping in of the sole bars from the leverage of the angle plates bolted to them to rest on the springs; it has also been necessary to truss horizontally the underframes to distribute the blows on the headstocks."

Stripped of technical terms, this simply means that the overhanging weight caused by narrowing the base on which the waggons and carriages run is telling seriously upon them, and they will apparently not have the durability of broad gauge stock.

The above classes of charges, maintenance, locomotive power and carriage and waggon expenses, are the ones in which the main difference

between the metre gauge and broad gauge must always lie, and on the relative cost of which the failure of the metre gauge to compete with the broad is proved.

Traffic charges and general charges may be the same for either class of Railway, for the same amount of business, the gauge has no effect upon them, but to complete the comparison, the totals of all, including these, are given (Table V.), and are, Rajputana 35·76 annas, Great Indian Peninsula 26·55, Bombay, Baroda and Central India 42·96.

This seems at first sight in favour of the metre gauge, but it is the same point again. Measured by the amount of duty which the train mile represents on the Bombay, Baroda and Central India, and which costs 42·96 annas, it is twice and one-third more than that on the Rajputana (see Table VI.)

To put it another way: if the duty per train mile on the metre gauge is brought to the same standard as on the Bombay, Baroda and Central India, its cost is 78·77 annas as against 42·96 annas for the Bombay, Baroda and Central India.

Another important comparison is the duty done by each locomotive, the average daily mileage is, Rajputana 40·29 miles, Bombay, Baroda and Central India 58·5 miles. The average gross train is, Rajputana 111·28 tons, Bombay, Baroda and Central India 316·5 tons, (the Great Indian Peninsula account is incomplete). Multiplying these figures, one by the other, gives the ton mileage duty done by the engines, and the figures are, Rajputana 4,483, Bombay, Baroda and Central India, 18,515 ton miles.

The duty done by a Bombay, Baroda and Central India Railway locomotive engine is more than four times that done by the metre gauge engine.

There are other figures showing that the broad gauge takes a larger number of vehicles in a train and more in each vehicle. That the average gross train load of the Rajputana is about 123 tons, of the Great Indian Peninsula 170 tons, and of the Bombay, Baroda and Central India 286 tons. That the percentage of working expenses to receipts is, Rajputana 68·11 per cent., Great Indian Peninsula 49·08, Bombay, Baroda and Central India, 42·84 per cent. The cost of carrying a unit of traffic is for passenger traffic, Rajputana 29·5 pies, Great Indian Peninsula, 17·41 pies, Bombay, Baroda and Central India 19·61 pies; or for

goods traffic, Rajputana 7.79 pies, Great Indian Peninsula 4.59 pies, Bombay, Baroda and Central India 4.82 pies. These last are most important figures, as showing the net result of all charges distributed over the work.

All these particulars are taken from the accounts audited by Government, and may be perfectly relied upon. With regard to the Great Indian Peninsula it may be pointed out that the year 1877 was the famine year, and the profits made large, but this does not favourably influence the figures which have been the subject of comparison above: on the contrary, the mileage and tonnage expenses are the worse for this, and it cannot be said that the Rajputana suffers unfairly by comparison with an abnormal year on the Great Indian Peninsula. This is not the case.

All the figures quoted point in the same direction—the metre gauge may make a good profit. This is a question of its first cost—or the charges per train mile may in some things be moderate: this is because the train is very small. But in every case where it is judged by the actual work done in tonnage, number, and distance, it is far inferior to the broad gauge.

No other result could be expected. It never can be an economical arrangement to employ two or three trains and four locomotives to do the work now done by one train and locomotive; yet this is what it has been wilfully elected to try upon the Rajputana Railway.

The object of these remarks is to show the facts and not to disparage the narrow gauge. Let it therefore get credit for the cases where it is serviceable. Just because its line, engine and train are small it would work more economically where the traffic is proportionately small and not enough to usefully employ the broad gauge, the same as it is cheaper to employ a boy to do boy's work and a man to do man's.

But the narrow gauge should never have been upon the Rajputana district between Bombay, Delhi, and Agra. On this line and with this traffic, which is destined to increase largely above what it is now, the small size is a positive hindrance: it will always be a deadweight upon the traffic, making it more expensive, slower, and more inconvenient.

It has already been shown that the cost of construction of the Rajputana line is coming up to or exceeding that for which broad gauge lines have been built.

That owing to the small comparative capacity of the Rajputana metre gauge, its stock must be very numerous to meet the requirements of the broad gauge lines with which it connects, and the extra cost of this stock will absorb any saving which would be on the line alone.

At the same time the figures of actual working lead irresistibly to the conclusion that traffic must always cost more to convey over this metre gauge line than had it been a broad gauge.

We have, therefore, the result that breaks of gauge have been artificially created at Delhi, at Agra, and to be at the station where the Bombay, Baroda and Central India will be joined. That we have a line of inferior capacity unable to meet an emergency, and that must cost more to work than broad gauge. This deplorable result is being obtained without the prospect of saving a single rupee in capital outlay and with the certainty of an inferior revenue in the future.

TABLE I.

Total Working Expenses and Profits for the year 1877.

	Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
Capital expended, £	2,538,240	22,145,353	7,538,220
Percentage of profits,	3.43	6.98	5.50
Earnings, Rs.	26,96,687	3,27,74,150	77,98,912
Expenses, Rs.	18,33,367	1,58,28,633	32,73,330
Profits, Rs.	8,63,320	1,69,45,467	45,25,582
Percentage of expenses to earnings, ...	68.11	49.03	42.84
Earnings per train mile, Rs.	3.25	3.87	6.38
Expenses „ Rs.	2.21	1.88	2.70
Profits „ Rs.	1.04	1.99	3.68

TABLE II.

Working Expenses Maintenance of Line for the year 1877.

	Rajputana		Great Indian Peninsula		Bombay, Baroda and Central India	
Mileage of line maintained, ...	396.30		1278.76		430.78	
Ton mileage,	120,876,767		2,119,222,775		376,721,980	
	Per mile of line maintained	Per 1,000 ton miles	Per mile of line maintained	Per 1,000 ton miles	Per mile of line maintained	Per 1,000 ton miles
	Rs.	Ra.	Rs.	Ra.	Ra.	Ra.
General Superintendence, ...	158.56	1.04	154.86	0.190	224.86	0.33
Maintenance and renewal of permanent way,	300.19	1.95	780.04	0.955	436.34	1.03
Repairs of bridges,	13.63	0.09	115.25	0.141	353.27	0.73
Repairs of stations and buildings, ...	30.08	0.20	76.70	0.093	84.34	0.21
Maintenance by contract, ...	56.42	0.37	...	...	8.90	0.02
New minor works,	15.95	0.13	2.40	0.003	...	...
Unclassified expenditure, ...	13.05	0.08	17.56	0.022	18.00	0.05
Less,	...	...	1146.81 429.70	1.404 0.527	1125.71 14.33	2.57 0.03
Total, ...	587.88	3.83	717.11	0.877	1111.38	2.54

TABLE III.

Working Expenses Locomotive Power for the year 1877.

	Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
Train mileage,	828,012	8,430,578	1,207,599
Ton mileage,	120,876,767	2,119,222,775	376,721,980

COMPARATIVE WORKING EXPENSES ETC.

11

	Per train mile	Per 1,000 ton miles	Per train mile	Per 1,000 ton miles	Per train mile	Per 1,000 ton miles
	As.	Rs.	As.	Rs.	As.	Rs.
General Superintendence, ...	1.05	0.48	0.58	0.15	1.31	0.27
Driving,	3.88	1.45	2.57	0.64	2.05	0.42
Cleaning, fuelling,	0.28	0.12	0.41	0.10	0.58	0.09
Coal and other fuel,	5.74	2.46	5.85	1.45	5.88	1.19
Repairs and renewals,	2.14	0.89	1.96	0.49	2.35	0.50
Water, oil and minor charges, ...	1.00	0.43	0.72	0.18	0.57	0.11
Total, ...	13.59	5.83	12.09	3.01	12.74	2.58

It costs the Rajputana Railway for Locomotive power to haul 1,000 tons 1 mile, Rs. 5.83.

It costs the two broad gauge lines Great Indian Peninsula and Bombay, Baroda and Central India Rs. 3.01 and 2.58 respectively to do the same work.

TABLE IV.

Working Expenses Carriage and Waggon Department for the year 1877.

	Rajputana		Great Indian Peninsula		Bombay, Baroda and Central India	
Train mileage,	828,012		8,430,578		1,207,599	
Vehicle mileage,	18,543,244		172,478,568		31,314,236	
	Per train mile	Per 1,000 vehicle miles	Per train mile	Per 1,000 vehicle miles	Per train mile	Per 1,000 vehicle miles
	As.	Rs.	As.	Rs.	As.	Rs.
General Superintendence, ...	0.30	0.83	0.16	0.49	0.45	1.12
Repairs and renewals—						
Coaching,	1.28	3.05	0.63	12.72	0.65	5.63
Goods,	0.82	4.06	3.41	12.28	1.50	5.20
Cleaning, oiling, and other expenses,	0.40	1.15	0.45	1.33	0.43	1.03
Total, ...	2.80	7.82	4.65	14.21	3.08	7.41

The Great Indian Peninsula is abnormally high, the Bombay, Baroda and Central India is about a fair average, and is lower per 1,000 vehicle miles of large stock than the Rajputana with small stock. The Rajputana stock is also nearly new and should require little repair, the Bombay, Baroda and Central India is rebuilding and heavily repairing a considerable proportion of stock.

TABLE V.

Working Expenses Total per Train Mile for the year 1877.

	Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
	Per train mile	Per train mile	Per train mile
	Annas.	Annas.	Annas.
Maintenance,	8-99	3-53	12-56
Locomotive expenses,	13-59	12-08	13-79
Carriage and waggon expenses, ...	2-80	4-64	3-03
Traffic expenses,	4-61	4-31	7-67
General charges,	5-77	1-99	6-71
Total, ...	35-76	26-55	43-96

The total per 1,000 ton miles is not given, but the total per unit of traffic is given in Table VIII.

TABLE VI.

Average Weight of Trains for the year 1877.

	Freight	Train	Total
	Tons.	Tons.	Tons.
RAJPUTANA STATE RAILWAY.			
Passenger trains,	12-33	87-73	100-06
Goods trains,	55-29	95-55	150-84
Mixed trains,	27-42	91-20	118-62
GREAT INDIAN PENINSULA RAILWAY.			
Passenger trains,	12-47	89-96	102-43
Goods trains,	89-53	180-15	219-68
Mixed trains,	60-16	127-67	187-83

	Freight	Train	Total
BOMBAY, BARODA AND CENTRAL INDIA RAILWAY.	Tons.	Tons.	Tons.
Passenger trains,	12.28	108.46	120.74
Goods trains,	188.50	276.86	459.86
Mixed trains,	88.12	194.81	277.93
			286

The approximate average gross weights of the three classes of trains upon the three Railways are—

Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
123	170	286

The cost of hauling these Trains for Locomotive power only is respectively:—

Annas	Annas	Annas
13.59	12.09	12.74

TABLE VII.
Duty done by Stock for the year 1877.

	Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
Average daily run of locomotives, ... Miles	40.29	84	58.5
Average gross train load goods and passenger together, ... Tons	111.28	...	316.5

Relative value of duty done by locomotives is represented by average gross load into average daily run—as follows:—

Rajputana,	$111.28 \times 40.29 = 4,488$
Bombay, Baroda and Central India, ...	$316.5 \times 58.5 = 18,515$

The figures of the Great Indian Peninsula are not complete, so comparing Bombay, Baroda and Central India only, we find it has more than four times the duty done by each locomotive than the Rajputana.

	AVERAGE NUMBER OF VEHICLES PER TRAIN.		
	Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
Passengers,	22	16	14
Goods,	24	24.75	50
Mixed,	8	18.7	18

TABLE VIII.

Duty done by Stock, &c., for the year 1877—(Continued).

	AVERAGE FREIGHT OR LIVE LOAD		
	Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
Passenger, Tons	12.32	12.46	12.28
Goods, "	55.28	89.50	183.50
Mixed, "	27.41	60.15	83.12

	AVERAGE CONTENTS OF GOODS VEHICLES
Rajputana,	2.31 Tons.
Great Indian Peninsula,	8.89 "
Bombay, Baroda and Central India,	8.74 "

	COST OF CARRYING ONE MILE A UNIT OF TRAFFIC		
	Rajputana	Great Indian Peninsula	Bombay, Baroda and Central India
Average of all descriptions of passenger traffic,	Pies. 29.5	Pies. 17.41	Pies. 19.61
Goods,	7.79	4.59	4.12

Memorandum on Mr. Carroll's Paper on a comparison between Broad and Metre Gauge Railways. BY LIEUT. H. PILKINGTON, R.E., Acting Deputy Consulting Engineer for Railways.

Bombay, 1st March, 1879.

1. In a paper on the above subject, Mr. Carroll has selected the year 1877 to make a comparison between the Rajputana Metre Gauge Railway and the Great Indian Peninsula and Bombay, Baroda and Central India Broad Gauge Railways; but the year 1877 was a special one with regard to the two latter lines, as their receipts were so largely increased by the famine grain traffic.

2. During the first half of 1877 the Great Indian Peninsula paid a percentage of £4.18 for the half-year on the capital expended; this is the highest percentage yet reached, and it is probable that so prosperous a

half-year will not occur again for some time. The percentages for the corresponding half of 1875 and 1876 were £3·13 and £2·97, respectively.

3. From the table given below, it will be seen that 1877 was an exceptional year for the Great Indian Peninsula and Bombay, Baroda and Central India Railways, and the large increase in receipts and proportionally higher percentage cannot be taken as an estimate for future years—

	Earnings	Expenses	Percentage of Expenses to Earnings	Sum of two half-yearly Dividends on Capital expended, including Rolling Stock	Increase
	Rs.	Rs.		£	
Great Indian Peninsula 1875, ...	2,15,24,577	1,01,75,860	47	4·77	...
Do. 1876, ...	2,45,35,412	1,16,77,891	48	5·38	0·61
Do. 1877, ...	3,27,74,150	1,58,28,683	49	6·98	1·60
Bombay, Baroda and Central India 1875, ...	63,86,783	34,75,021	54	3·58	...
Do. 1876, ...	67,72,292	37,11,564	54	3·75	0·17
Do. 1877, ...	77,98,912	32,73,330	43	5·50	1·75

The percentages of profits on capital expended, including rolling stock, on the Rajputana line for the same three years was—

	Earnings	Expenses	Percentage of Expenses to Earnings	Sum of two half-yearly Dividends on Capital expended, including Rolling Stock	Increase or Decrease
	Rs.	Rs.		£	
Rajputana 1875, ...	17,46,960	11,18,691	64	3·480	...
Do. 1876, ...	23,29,592	15,23,622	65	3·484	+·004
Do. 1877, ...	26,96,687	18,33,368	68	3·434	-·050

but extra capital to the amount of £411,882, or over £1,000 per mile, was expended during the two latter years, which accounts, to a great extent, for the small percentage of profits. The earnings are steadily increasing, and it is probable that such increase will be maintained for some time to come, and that a more favourable percentage of profits will be shown.

4. The first portion of the Rajputana line was opened in 1873, and to Ajmere in 1875. It was the first metre gauge system opened to traffic and worked as a State line, and experience has to be purchased at some expense, although not to the same extent as when the guaranteed railways were first opened. As the line grows older, the working arrangements will become more complete, and new lines will be constructed at less cost. It is not, therefore, unreasonable to suppose that greater economy and efficiency will be the result.

5. The average number of trains each way over each mile of line, during 1877, was on the Rajputana line 2·87, and on the Great Indian Peninsula 9·00, so that it will be seen that the narrow gauge was not working up to anything like its carrying capacity. A newly opened line is always at a disadvantage with regard to other lines of longer standing; there is generally a want of proper roads to bring goods to the railway, and it takes time before traffic flows into a new channel. For this reason it would be fairer to compare the Rajputana with the Nizam's line. Both are branch lines situated far away from the sea; they have no large emporium of trade, such as Bombay, for a terminus, and they have to pay largely for the carriage of coal and stores from the port where they are landed. The figures given for the Nizam's line are not absolutely correct, but they are returned by the Great Indian Peninsula as the estimated cost to the Company under the various headings. Some of the figures of the Bombay, Baroda and Central India working during 1866, namely, two years after it was opened through to Ahmedabad, have also been taken for the purpose of comparison.

6. With reference to the cost of construction of a narrow gauge line, the comparison with the Wadhwan and Dákor extensions is, I think, hardly fair, as the work on these latter lines is exceptionally light, and no capital expenditure on rolling stock was incurred. A metre gauge line is undoubtedly cheaper to construct than a broad gauge line under the same circumstances. It is, however, hardly possible to arrive at any figure which would give a reliable comparison between the cost of construction of the two systems. According to the analysis of the revenue account the cost per mile of the—

Great Indian Peninsula			
has been	...	...	£ 17,329, including rolling stock, $\frac{1}{4}$ th double line.
Bombay, Baroda and Cen-			
tral India has been	...	„ 16,975,	do. $\frac{1}{4}$ th do.
Rajputana (metre) has been	„	6,404,	do. all single.

Nizam's (broad gauge)
 has been ... £ 8,828, without rolling stock, all single.
 Wardha Valley (broad
 gauge) has been ... „ 9,999, do. do.

but Mr. Carroll rightly calls the Great Indian Peninsula and Bombay, Baroda and Central India pioneer lines, and there are many special circumstances to account for the large sum spent on their construction.

7. As to the metre gauge stock carrying "about half the number of passengers or weight of goods" that is carried by the broad gauge, it will be seen from Mr. Carroll's figures, Table VIII. for 1877, that practically the average weight or live load of a metre gauge passenger train on the Rajputana State Railway is 12·32 tons, while on the Great Indian Peninsula it is 12·46 tons, and on the Bombay, Baroda and Central India 12·28 tons, thus the metre gauge train carried *more* passengers than the Bombay, Baroda and Central India train, and very nearly as many as the Great Indian Peninsula, although, no doubt, the carrying capacity of the broad gauge stock is greater.

8. The average contents of a metre gauge goods wagon was 2·31 tons against 3·89 tons on the Great Indian Peninsula, and 3·74 tons on the Bombay, Baroda and Central India; or, taking the average of the broad gauge, the proportion would be as 1 : 1·65.

9. Comparing the working expenses of the different lines, it is observed that in Table II. of Mr. Carroll's paper "Maintenance of Line," the figures do not give the actual maintenance charges, as the amounts debited to special funds on the Great Indian Peninsula Railway have been deducted. As these funds contributed largely to the maintenance of the line, they should be included, and the real charges will be—

Rajputana, ...	Rs. 1,175·76	per mile, or	Rs. 3·85	per 1,000 ton miles.
Great Indian Peninsula, „	2,287·48	„	1·38	do.
Bombay, Baroda and				
Central India, ... „	2,250·86	„	2·57	do.

Thus, the actual maintenance cost of the Rajputana line is about half that of the Great Indian Peninsula or Bombay, Baroda and Central India, due, in a great measure, as Mr. Carroll observes, to the short time the line has been opened; but, as has been before pointed out, the traffic on the metre gauge line was very small compared with its capabilities, and only required about one-third the number of trains run on the Great Indian Peninsula; the charges for maintenance consequently appear high

when compared with the number of tons of goods hauled. With regard to the locomotive expenses, the working of a metre gauge engine can hardly be expected to compare favourably with that of the broad gauge with the same amount of traffic; but the traffic on the Rajputana line was light for the number of engines at work, whereas the Bombay, Baroda and Central India engines were working nearly at a maximum.

10. From the following table of locomotive working expenses—

	Cost per train mile	Cost per 1,000 ton miles
	As.	Rs.
Rajputana,	13-59	5-83
Nizam's (broad gauge),	13-65	4-31
Great Indian Peninsula,	12-09	3-01
Bombay, Baroda and Central India,	12-74	2-58

it will be seen that the Rajputana line compares unfavourably with the broad gauge in the cost per 1,000 ton miles owing to the lighter loads per train, but the comparison of cost per train mile is very favourable, considering the disadvantages of the newly opened branch lines.

11. The carriage and wagon expenses are considerably less on the Rajputana than on the broad gauge lines, but this is accounted for by the comparatively new stock on the former line, as pointed out by Mr. Carroll.

12. The traffic expenses per train mile on the three lines are—

Rajputana,	4-61 annas.
Great Indian Peninsula,	4-31 "
Bombay, Baroda and Central India,	7-87 "

The amount given for the Rajputana line in Mr. Carroll's paper is 2-61, but this is probably a misprint.

13. The general charges per train mile are—

Rajputana,	5-77 annas.
Great Indian Peninsula,	1-99 "
Bombay, Baroda and Central India,	6-71 "
Nizam's,	5-01 "

but the shorter lines are always at a disadvantage in this respect, as the general administration would suffice for a longer line and more traffic.

14. In both traffic and general charges the comparison is favourable, under the circumstances, to the metre gauge line.

15. The total working expenses per train mile are—

Rajputana,	85-77 annas.
Great Indian Peninsula,	28-58 "
Bombay, Baroda and Central India,	43-24 "
Nizam's,	36-67 "

These figures differ slightly from Mr. Carroll's, owing to the corrections made in maintenance charges. The total working expenses per train mile on the Rajputana line are less than on the Nizam's, and considerably less than on the Bombay, Baroda and Central India.

16. The cost of carrying one ton of goods one mile is—

Rajputana, 1877,	7-79 pies.
Nizam's (broad gauge), 1877,	7-91 "
Great Indian Peninsula, 1877,	4-59 "
Bombay, Baroda and Central India, 1877,	4-12 "
" " " (two years after through running), 1866,	17-38 "

The cost per ton mile depends on various circumstances, such as price of fuel and labour, gradients, character and direction of traffic, &c. The cost on the Rajputana line is a good deal higher than on the Bombay, Baroda and Central India, but it must be remembered that the gradients are considerably longer and heavier on the narrow gauge line, as will be seen from the following table :—

	TOTAL LENGTH OF THE FOLLOWING GRADIENTS			Total mileage of line
	1 in 100 & less	1 in 101 to 1 in 200	1 in 201 to 1 in 300	
	Miles.	Miles.	Miles.	
Rajputana,	2-62	85-65	44-51	396-30
Bombay, Baroda and Central India, ..	27	54	9-69	430-78

The price of fuel on the Rajputana line was from Re. 1 to Rs. 2 per ton dearer than on the Bombay, Baroda and Central India. The cost per ton mile on the Rajputana line is less than on the Nizam's, but if we compare the metre gauge line, which has only been open through for two years, with the Bombay, Baroda and Central India under similar conditions in 1866,* we find that it carries one ton at less than half the cost of the broad gauge, the inference being that the Rajputana line, as it becomes developed, will be able to reduce its carrying expenses.

* Note.—The cost of carriage per ton mile was, however, calculated somewhat differently in 1866

17. In calculating the duty done by each locomotive, the average gross train loads should be—

Rajputana,	111.8 tons.
Great Indian Peninsula,	205.0 "
Bombay, Baroda and Central India,	255.1 " (not 316.5).

This is found by taking the total ton mileage plus that of brake vans, and dividing by the total train mileage for the year. The ton mileage duty done daily by the engines will then be—

Rajputana,	4,484
Bombay, Baroda and Central India,	14,923

or in the proportion of 1 : 3.32 instead of 1 : 4.13.

But it has been previously stated that the engines of the Bombay, Baroda and Central India were much more fully employed than those on the Rajputana line, owing to the small amount of traffic that was brought on to the latter line.

18. Mr. Carroll says that "it is cheaper to employ a boy to do a boy's work, and a man to do a man's," and he argues not so much that the metre gauge line is a mistake altogether, but that it is a mistake to have adopted it on the Rajputana line. The comparison, however, has been made with the Rajputana line as it stands at present.

19. Putting aside the question of future extension, let it be supposed that the broad gauge had been adopted. The amount of traffic carried and the receipts would still be the same. The working expenses would certainly not be smaller, unless the line were worked as a branch of the adjacent guaranteed railways, while the interest would have to be paid on capital outlay of, at least, £2,000 a mile more, judging from the cost of the Nizam's and Wardha Valley lines. It would follow then that the interest on the extra cost of construction would swallow up a large amount of the profits, and although there might be a possibility of larger receipts in future years from a broad gauge line, there would be the certainty of a smaller percentage on capital expended during the first years of the line being opened.

20. It is proposed here to enter into the general question of Broad *versus* Narrow Gauge, or the disadvantages of break of gauge, but only to show that as far as the Rajputana line itself is concerned, a fair percentage has been returned on a comparatively small original outlay, and that the metre gauge line is capable of carrying three times the present traffic without doubling the line.

By MR. J. O'CONNELL, *Chief Auditor and Accountant, Bombay, Baroda and Central India Railway.*

Bombay, 9th May 1879.

1. Lieutenant Pilkington commences his memo. on Mr. Carroll's paper by pointing out that the year selected for a comparison of the cost of working the Bombay, Baroda and Central India and the Great Indian Peninsula broad gauge lines, with the Rajputana metre gauge line, was an exceptionally prosperous one for the broad gauge lines in consequence of the large famine grain traffic, thereby implying that the comparison is unfair to the narrow gauge line.

2. Now it is well known that the increase in this description of traffic was not confined to the Great Indian Peninsula and Bombay, Baroda and Central India lines, but that it extended all over India, and it will be seen from the following figures that the increase in quantity on the Rajputana line was even greater in proportion (as compared with the previous year) than it was on either of the broad gauge lines :—

	1877		1876		Increase		Equal to per cent over 1876	
	Tons	Receipts	Tons	Receipts	Tons	Receipts	Tons	Receipts
		Rs.		Rs.		Rs.		Rs.
Great Indian Peninsula Railway,	735,594	1,21,53,134	424,546	58,28,695	311,048	63,24,439	73.27	108.51
Bombay, Baroda and Central India Railway, ..	119,636	8,97,129	62,923	4,04,346	56,713	4,92,783	90.13	121.87
Rajputana Railway,	38,223	1,83,871	16,050	1,03,640	22,173	80,231	138.15	77.41

3. It appears, however, that the comparatively larger increase in the grain traffic of the narrow gauge line did not bring with it a corresponding increase in the receipts, owing to its having been conveyed shorter distances than on the broad gauge lines.

4. On the other hand the Rajputana line had an increase of Rs. 2,18,943,

or about 43 per cent. in its receipts from Salt Traffic, *viz.*, from Rs. 4,97,427 to Rs. 7,11,370; while the Bombay, Baroda and Central India had an increase in this traffic of only Rs. 50,252 (20·58 per cent.) and the Great Indian Peninsula Company, a *decrease* of Rs. 83,608, although they carried 1,789 tons *more* than in 1876. This traffic which forms over 46½ per cent. of the whole of the goods traffic of the Rajputana State Railway commands a higher rate than the grain traffic, and is, according to Major Dowden's Notes on the Rajputana line accounts for December 1877, 30 per cent. higher than the Bombay, Baroda and Central India Company's salt rate; the former being 9·55 pies per ton per mile, the latter only 7·35. Their rates for grain and sugar were also higher than the Bombay, Baroda and Central India Company's, the respective rates being :—

	Grain	Sugar
Bombay, Baroda and Central India, ... }	8·15 pies per ton per mile.	10·65 pies per ton per mile.
Rajputana, ...	8·75 " "	11·60 " "

5. But taking the whole of the goods traffic of the line, and comparing the rate received per ton mile with the rates received on the broad gauge lines, it will be seen that the average rates of the narrow gauge were nearly 29 per cent. higher than the Bombay, Baroda and Central India, and 56½ per cent. higher than the Great Indian Peninsula Company's, the respective rates per ton mile being :—

	Pies
Great Indian Peninsula,	8·81 per ton per mile.
Bombay, Baroda and Central India,	10·70 "
Rajputana,	13·79 "

Had the goods traffic of the narrow gauge line been carried at the same average rate per ton per mile as the traffic of the broad gauge lines, the gross earnings from goods traffic would have been reduced from Rs. 17,25,864 to Rs. 11,02,856 at the Great Indian Peninsula Company's rates, and to Rs. 13,39,451 at the Bombay, Baroda and Central India Company's rate.

6. Comparing now the whole of the goods traffic of the narrow gauge line with the previous year, it appears that the increase in its receipts was comparatively 68 per cent. greater than the increase in the Bombay, Baroda and Central India Company's receipts; the totals (tonnage and receipts) being as follows :—

	1877		1876		Increase		Equal to per cent. over 1876	
	Tons	Receipts	Tons	Receipts	Tons	Receipts	Tons	Receipts
		Rs.		Rs.		Rs.		Rs.
Great Indian Peninsula Railway,	1,514,727	2,54,98,616	1,286,741	1,84,90,546	277,986	70,08,070	22.48	37.90
Bombay, Baroda and Central India Railway, ..	538,009	46,43,011	457,461	40,87,138	80,548	5,55,873	17.61	13.60
Rajputana Railway,	204,809	17,25,865	166,298	14,04,978	38,511	3,20,887	23.16	22.84

7. It should also be noticed here that in addition to the rate per ton mile earned on the broad gauge lines being so much lower than on the narrow gauge line, they conveyed a considerably larger quantity of stores *free* on Revenue account, the tonnage and ton mileage on such stores being as under :—

	Tons.	Ton miles.
Great Indian Peninsula,	2,76,558	40,909,542
Bombay, Baroda and Central India,	47,674	56,18,294
Rajputana,	32,741	27,56,947

8. The foregoing facts show, I think, conclusively that there was nothing whatever unfair towards the narrow gauge line in selecting the year 1877 for a comparison with the broad gauge, especially as Mr. Carroll's paper was written not with the object of comparing the earnings but the working cost.

9. With reference to paragraph 3 of Lieutenant Pilkington's memo. the dividends quoted, are the sum of the two half-yearly amounts; this mode of arriving at the yearly dividend does not affect the broad gauge Railways, as their capital varies so slightly from half-year to half-year; the dividend rates as shown are, therefore, correct on the capital as it stood at the close of each year, but as the same rule does not apply to the Rajputana State Railway, the dividends should have been shown thus—

	Per cent	instead of	Per cent
1875,	2.71		3.48
1876,	3.10	„	3.484
1877,	3.12	„	3.434

10. At the conclusion of paragraph 3 of his memo., Lieutenant Pilkington states that, "the earnings are steadily increasing, and it is probable that such increase will be maintained for some time to come, and that a more favourable percentage of profits will be shown." Now, bearing in mind, that as the line gets older the cost of maintenance will increase as well as the expenditure on the repairs and renewals of engines and rolling stock, the prospect of a more favourable percentage is, therefore, I consider somewhat doubtful. It should also be remembered that to meet the requirements of increased traffic, further capital outlay will be necessary for additional engines and other rolling stock, the present engine power being, it would appear, inadequate even to the requirements of the year 1877. This I gather from the Manager's Note on the accounts for December 1877, in which he says that, "extra expenses may have been caused in working from overloading of engines." Had the engine power been equal to the requirements, the capital outlay would have been greater, and the percentage of profit consequently less.

11. In paragraphs 5 and 9, Lieutenant Pilkington states that, "the narrow gauge line was not working up to anything like its carrying capacity, and that the traffic was very small compared with its capabilities," and he concludes his memo. by stating that, "the line is capable of carrying three times its present traffic without doubling it." Now it is evident from the Manager's Note that so far as locomotive power is concerned the line was doing its utmost, therefore presuming there were three times the amount of traffic to carry at least three times the number of engines, and a very large addition to the rolling stock would be necessary; even then it is extremely doubtful whether, considering the low rate of speed on the Rajputana line, three times the present number of trains, (*viz.* 2·87) could be run, as it is well known that the Great Indian Peninsula Company, although running at a much higher speed than the Rajputana, found great difficulty in working an average of nine trains per day each way.

12. In paragraph 6 Lieutenant Pilkington says that he considers, "the comparison of cost of construction with the Wadhwan and Dákor extensions hardly fair, as the work on these latter lines is exceptionally light, and no expenditure on rolling stock was incurred. Although no expenditure was actually incurred on this account, Mr. Carroll made due allowance for it as well as for workshops, offices, &c., in making a comparison with the Rajputana line, see page 3 of his paper. He also makes

due reference to "the favourable conditions under which the lines were constructed," see also page 3. There is consequently nothing unfair in comparing the cost of construction of these extensions with the cost of the Rajputana line.

13. With reference now to the comparative cost of working, Lieutenant Pilkington shows that the respective cost per mile maintained on the three lines was—

	Rs.	Rs.
Great Indian Peninsula, ...	*2,287.48 per mile or 1.88 per 1,000 ton miles.	
†Bombay, Baroda and Central India, total, ...	2,250.86	2.57
Rajputana, ...	1,175.76	3.85

The cost per mile maintained of the Great Indian Peninsula was 22½ per cent. more, and that of the Bombay, Baroda and Central India was nearly double that of the Rajputana line. But the cost per 1,000 ton miles on the latter line was 88 per cent. more than the Bombay, Baroda and Central India, and nearly 3.48 per cent. more than the Great Indian Peninsula.

14. The lower cost per mile maintained on the Rajputana line being due, as pointed out by Mr. Carroll, to the short time the line has been opened, amount of work done in the shape of renewals of rails and sleepers being a mere trifle as compared with that of the broad gauge lines, as will be seen from the following particulars:—

	Bombay, Baroda and Central India Railway	Great Indian Peninsula Railway	Rajputana State Line
<i>Rails.</i>			
Rails inverted, { Number, ...	3,538	20,153	...
Miles, ...	13.5507	84.145	...
Rails renewed, { Number, ...	1,145	15,682	5.28
Miles, ...	4.4355	66.317	2.39

	Bombay, Baroda and Central India Railway		Great Indian Peninsula Railway		Rajputana State Line	
	Removed	Relaid	Removed	Relaid	Removed	Relaid
<i>Sleepers.</i>						
Wooden, { Number, ...	24,665	17,308	83,572	40,328	9,073	9,231
L. yards, ...	22,646	22,646	...	...	956	498
Iron, ... Pairs, ...	30	7,887	12,171½	60,415½	...	...

15. Had the maintenance of the Rajputana line been done at the same

* (Should be Rs. 1,434 and 0.88).

† Exclusive of Special Expenditure amounting to Rs. 1,36,476 the rate per mile maintained was Rs. 1,789.24 or Rs. 2.04 per 1,000 ton miles.

rate per 1,000 ton miles as on the broad gauge lines, the total cost under that head would have been reduced from Rs. 4,65,954 to Rs. 1,03,954 at the Great Indian Peninsula rate, and to Rs. 2,46,588 at the Bombay, Baroda and Central India rate.

16. With reference to the Locomotive expenses, Lieutenant Pilkington's statement in paragraph 9, that the traffic on the Rajputana line was light for the number of engines at work, does not, as I have already shown in paragraph 10, agree with the Manager's statement regarding "the overloading of engines." And with reference to his remark in paragraph 10, that "the comparison of cost per train mile is very favourable considering the disadvantage of the newly-opened branch lines." It appears to me that their engines being comparatively new, the disadvantage lies with the broad gauge lines. But the cost per train mile is not a fair test of the Locomotive working expenses, the ton mile forms a much fairer basis of comparison, and that shows that the Rajputana cost nearly double the Great Indian Peninsula and more than double the Bombay, Baroda and Central India, their respective rates being, as shown by Mr. Carroll—

Rajputana,	Rs. 5.83 per 1,000 ton miles.
Great Indian Peninsula,	3.01 " "
Bombay, Baroda and Central India, ..	2.58 " "

17. Applying then the broad gauge rates to the Rajputana line, their Locomotive expenses would have been reduced from Rs. 7,03,878 to Rs. 3,63,839 at the Great Indian Peninsula rate, and to Rs. 3,11,862 at the Bombay, Baroda and Central India rate; and applying even the train mile test to the cost of running, the Rajputana rate was 23 per cent. higher than the Great Indian Peninsula, and 39 per cent. higher than the Bombay, Baroda and Central India, the respective rates being—

	Annas
Great Indian Peninsula,	2.98
Bombay, Baroda and Central India,	2.63
Rajputana,	3.66

Consequently in the cost of running alone the Rajputana line expended Rs. 34,842 more than if they had been able to do the work at the same rate as the Great Indian Peninsula Company, and Rs. 52,955 more than at the Bombay, Baroda and Central India Company's rate. This is, of course, the result of having to employ at least three times the number of drivers and firemen to work the same amount of traffic as on a broad gauge line with their more powerful engines and rolling stock

of superior capacity. The cost under wages of drivers and firemen on the Rajputana line was over 35 per cent. more than on the Bombay, Baroda and Central India in the second half of the year, *viz.*, Rs. 88,898 against Rs. 65,737.

18. The carriage and wagon expenses per vehicle mile compare favourably with the broad gauge lines, but this is owing, as pointed out by Mr. Carroll, to the Rajputana stock being nearly new, whereas the Bombay, Baroda and Central India Company were rebuilding and heavily repairing a considerable proportion of their stock. The average number of vehicles constantly under repair during the year on the respective lines being—

Great Indian Peninsula,	...	...	...	...	1,087
Bombay, Baroda and Central India,	...	...	...	...	194
Rajputana,	...	...	...	...	78

The expenditure, under this head, as well as under the head of Maintenance of Permanent Way, on the Rajputana line will, as already observed, increase as the line gets older.

19. The comparison of traffic expenses in paragraph 12 of Lieutenant Pilkington's Report is correct so far as the figures go, but the basis (*viz.*, the train mile) upon which it is made, is not a fair test, the comparison should be made on the ton mile, which shows the following results:—

Great Indian Peninsula,	...	...	Rs. 1.06 per 1,000 ton miles.
Bombay, Baroda and Central India,	„	1.57	„
Rajputana,	...	...	„ 1.97 „

20. If the Rajputana line had been worked at the same rate per 1,000 ton miles as the broad gauge lines, their expenses would have been reduced from Rs. 2,39,018 to Rs. 1,28,129 at the Great Indian Peninsula Company's rate of working, and to Rs. 1,89,776 at the Bombay, Baroda and Central India Company's rate.

21. The expenses of the train staff on the narrow gauge line must necessarily be higher, in proportion, than on the broad, at least three and a half times the number of guards being required to work the same amount of traffic.

22. But there is another point which does not appear to have been taken into consideration by Lieutenant Pilkington, *i. e.*, the stations on the Bombay, Baroda and Central India line are, on an average, only 6 miles apart, while on the Rajputana line they are 9 miles; the wages of the Traffic Staff are also lower on the Rajputana line than on the Bombay,

Baroda and Central India, their average cost per station being only Rs. 2,608 as against Rs. 4,309; due allowance should, however, be made for the large amount of traffic dealt with at the stations of the Bombay, Baroda and Central India Railway, the average tonnage and number of passengers booked during the year at each station on the respective lines being—

	Average number of Passengers booked at each station	Average Tonnage forwarded from each station
Bombay, Baroda and Central India,	70,487	7,270
Rajputana,	80,015	4,551

The average amount of passenger work at each station on the broad gauge line was consequently 134 per cent. more, and the goods nearly 60 per cent. more. It would not, therefore, be unfair to assume that if the stations on the Rajputana line had had the same amount of work to do, their staff would have been increased by *at least* 50 per cent., their average cost per station would then have been Rs. 3,900. Assuming then, that their number of stations had been in the same proportion to the Bombay, Baroda and Central India Company's for the length of line worked, they would have had 22 stations more, consequently their expenditure under this head alone would have been increased by Rs. 85,800, this is equivalent to nearly 36 per cent. on their total traffic expenses, which would have averaged Rs. 2·68 instead of Rs. 1·97 per 1,000 ton miles.

23. On the other hand if the stations on the Bombay, Baroda and Central India Railway averaged the same distance apart as on the Rajputana line, they would have had only 49 stations instead of 74 to work. Assuming then, the average amount of work done at each station to have been the same as on the Rajputana line (and allowing 15 per cent. for higher rate of wages paid on the Baroda line) that Company's expenditure under the head of "Station Staff" would have been reduced from Rs. 3,18,864 to Rs. 1,46,657, their gross traffic expenses per 1,000 ton miles would then have been only Rs. 1·11 instead of Rs. 1·57.

24. With reference to paragraphs 13 and 14, as the difference in gauge does not affect the general charges, it is not necessary to enter into details, nor to compare the general charges of the respective lines. I would, however, again remark that the train mile test as applied by Lieutenant Pilkington is fallacious and misleading.

25. In paragraph 15 the train mile test is again applied to the total working expenses, and the following are the results shown :—

Great Indian Peninsula, ...	28-58 annas per train mile.
Bombay, Baroda and Central India, 48-24	" "
Rajputana, ...	35-77 " "

But applying the ton mile test the result would be—

Great Indian Peninsula, ...	1-4841 pies per ton per mile.	
Bombay, Baroda and Central India, 1-5732	" "	(Excluding special
Rajputana, ...	2-9121 " "	charges as per paragraph 13).

And excluding general charges it would be—

Great Indian Peninsula, ...	1-8392 pies per ton per mile.	
*Bombay, Baroda and Central India, 1-8183	" "	(Excluding special
†Rajputana, ...	2-4717 " "	charges as per paragraph 13).

26. Referring now to paragraph 19 of Lieutenant Pilkington's memo. wherein he says,—“let it be supposed that the *broad gauge* had been adopted. The amount of traffic carried and the receipts would still be the same. The working expenses would certainly not be smaller, unless the line were worked as a branch of the Guaranteed Railways.” His observation as to the traffic and receipts being still the same is probably applicable to the year under review, but if recent current reports are to be relied on, that the Rajputana Railway authorities are compelled to refuse large quantities of traffic brought to their stations for conveyance, then it does not apply, as the broad gauge line, with its higher rate of speed, more powerful engines and vehicles of superior carrying capacity (*viz.* 8½ tons as against 5) would have been able to cope with the traffic up to over three times the quantity of the narrow gauge line, and its receipts would have been increased accordingly; the average train load being on the Bombay, Baroda and Central India line 183½ tons, while that of the narrow gauge line was only 55½ tons.* With regard to the working expenses “not being smaller,” it is difficult to understand how Lieutenant Pilkington can have arrived at this conclusion after showing as he has done in paragraph 16, that the cost of carrying one ton of goods one mile on the respective lines was—

* Making due allowance for difference in Station Staff, as pointed out in paragraphs 22 and 23, the result would be Bombay, Baroda and Central India 1-2305 pies, Rajputana 2-6080 pies.

† The Bombay, Baroda and Central India engines could haul a train of over 400 tons. The narrow gauge engine could not haul more than 125 tons.

	Pica.
Rajputana,	7-79
Great Indian Peninsula,	4-59
Bombay, Baroda and Central India,	4-13

the cost on the Rajputana being nearly 70 per cent. higher than on the Great Indian Peninsula, and 89 per cent. higher than on the Bombay, Baroda and Central India line.

27. But taking the working expenditure of the respective lines, (exclusive of general charges,) I think, I have shown most conclusively in paragraph 25 that the charges would have been nearly 45·82 per cent. less per ton mile had the line been worked at the same rate as the Great Indian Peninsula line, and 46·66 per cent. less at the Bombay, Baroda and Central India Company's rate; applying then these rates to the Rajputana line, the ton mileage being 120,876,767, the expenditure (excluding general charges) would have been reduced from Rs. 15,56,121 to 8,43,115 at the Great India Peninsula Company's rate of working, and to Rs. 8,29,958 at the Bombay, Baroda and Central India Company's rate.

28. The percentage of expenditure to earnings and percentage of profit on capital outlay on the Rajputana line would then have been as under :—

	Gross expenditure	Percentage of Expenses to Earnings	Net Profit per cent. on Capital outlay at 31st December 1877
At Great Indian Peninsula Company's rate of working,	11,20,861	41·55	6·21
At Bombay, Baroda and Central India Company's rate of working,	11,07,204	41·06	6·26
At Bombay, Baroda and Central India Company's rate allowing for Station Staff, as per Note at foot of paragraph 25, ...	10,51,928	39·01	6·48
Instead of, ...	18,33,367	68·00	3·12

29. There are a few other points in Lieutenant Pilkington's memo. which I have not touched upon, as it will, I think, be clearly seen from the foregoing comparison, that for a large traffic the standard gauge is more suitable than the narrow.

Summary of the principal items referred to in the foregoing observations on Lieutenant Pilkington's Memo.

FOR THE YEAR 1877.					
		Great Indian Peninsula	Bombay, Baroda and Central India	Rajputana	Remarks
1. Miles open,	..	1982-18	444-07	896-80	
2. " of line maintained,	..	1978-76	480-78	896-80	
3. " of track "	..	1815-61	827-57	445-15	(Including sidings).
4. Ton miles,	..	2,119,292,775	876,721,980	120,876,767	* Including State Railways.
5. Train miles,	..	8,480,578	1,207,599	828,013	
6. Number of stations,	..	158	74	45	
7. Average distance apart,	..	8 miles.	6 miles.	9 miles.	
Capital expended, ..	£	22,145,868	7,538,220	2,538,240	
Percentage of profits,	%	6-98	5-50	3-12	
Gross earnings, ..	Ra.	8,27,74,150	77,98,912	26,96,687	
" expenditure, ..	"	1,68,28,688	87,73,380	18,38,867	
Net Profit, ..	"	1,69,45,467	45,25,532	8,68,820	
Percentage of expenses to earnings, ..	%	49-08	42-84	68-00	
Gross earnings per ton mile,	Pies.	2-97	8-97	4-28	
" expenditure, ..	"	1-43	1-67	2-91	
Profit, ..	"	1-54	2-80	1-37	
Cost OF MAINTENANCE, ..	Ra.	18,38,989	77,70,812	4,66,963	† Excluding Ra. 1,96,478 for special charges.
per mile of track maintained,	"	1,010-10	1,461-06	1,046-73	
line "	"	1,434-15	1,789-34	1,175-76	
per 1,000 ton miles,	"	.96	2-04	3-85	
LOCOMOTIVE EXPENSES, ..	"	63,56,573	9,65,492	7,03,378	
" "	"	3-01	2-58	5-88	
per 1,000 ton miles,	"				

FOR THE YEAR 1877.		Remarks	
		Bombay, Baroda and Central India	Rajputana
Great Indian Peninsula			
16. CARRIAGE AND WAGON EXPENSES,	Ra.	24,48,115	2,28,353
17. " " " " " " " "	per 1,000 ton miles, "	1-15	61
18. " " " " " " " "	" 1,000 vehicle "	14-16	7-29
19. Average number of vehicles constantly under repair, "	No.	1,087	194
20. TRAFFIC EXPENSES (Total), "	" " " " " " " "	22,56,926	5,90,869
21. " " " " " " " "	per 1,000 ton miles, "	1-06	1-57
22. Average cost of working each station, "	" " " " " " " "	6-061	4-809
23. Total number of passengers carried, "	" " " " " " " "	47,12,145	52,16,821
24. " tons of goods carried, "	" " " " " " " "	1,514,727	588,009
25. Average number of passengers booked at each station, "	" " " " " " " "	29,828	70,497
26. " tonnage of goods " " " " " " " "	" " " " " " " "	9,587	7,270
27. " receipt per ton per mile for goods traffic, "	" " " " " " " "	8-81	10-70
28. " cost " " " " " " " "	" " " " " " " "	4-59	4-12
29. " profit " " " " " " " "	" " " " " " " "	4-22	6-58
30. " capacity of goods vehicles, "	" " " " " " " "	6-50	8-10
31. " load " " " " " " " "	" " " " " " " "	8-89	8-74
32. " freight of goods " " " " " " " "	" " " " " " " "	89-58	188-50
33. " " " " " " " "	" " " " " " " "	12-47	12-28
34. " " " " " " " "	" " " " " " " "	60-16	88-12
35. " " " " " " " "	" " " " " " " "	24-75	50-00
36. " " " " " " " "	" " " " " " " "	16-	23-
37. " " " " " " " "	" " " " " " " "	13-7	18-
38. " " " " " " " "	" " " " " " " "	8-	8-

Note by Mr. A. M. RENDEL, Consulting Engineer for State Railways, to the SECRETARY OF STATE FOR INDIA, on a "Comparison of the Rajputana Metre Gauge Railway with the Great Indian Peninsula and Bombay, Baroda and Central India Standard Gauge Railways," by Mr. E. B. CARROLL, Locomotive Superintendent, Bombay, Baroda and Central India Railway Company.

30th May 1879.

Mr. Carroll, the Locomotive Superintendent of the Bombay, Baroda and Central India Railway, has issued, under date February 1879, a Paper entitled "Comparison of the Rajputana Metre Gauge Railway with the Great Indian Peninsula and Bombay, Baroda and Central India Standard Gauge Railways," in which conclusions are arrived at very much to the disadvantage of the metre gauge.

Being in a measure responsible for the adoption of the metre gauge in India, I have perused this Paper with some interest; and as it forms the foundation of a "memorial of the inhabitants of Bombay in public meeting assembled" to the Secretary of State, protesting against the line between Ahmedabad and Ajmere being made on that gauge, I propose to offer some remarks in reply.

For the purpose he had in view, it was of course necessary for Mr. Carroll to state the conditions of a fair comparison. He commences, therefore, by saying that the Rajputana, having in 1877 been open throughout its entire length since 1875, "the result of the railway's working, that is, the cost of running its trains, of its maintenance, &c., ought now to be about as good as they are ever likely to be, and to form a perfectly fair basis of comparison with other railways;" and he then proceeds to lay the results obtained in working the Rajputana in 1877, alongside those of the Great Indian Peninsula and the Bombay and Baroda in the same year.

If Mr. Carroll had looked back at the cost of working his own line, and the Great Indian Peninsula in years bygone, he would have found that they were perhaps at their worst, so far as working cost is concerned, at that period of their existence at which he states a line should be at about its best.

Even so late as 1871, a year which showed a great improvement over

previous years, he would have found the working cost of the Bombay and Baroda 6.39s. per train mile, against 4.84s. in 1877; of the Great Indian Peninsula 5.58s., against 8.39s. in 1877. The East Indian, I may add, was 8.62s. in 1871, against 2.59s. in 1877.

As an expert he should know that, as a great portion of the working expenses of a railway is independent of the quantity of traffic it carries, the cost of transport upon it is highest when its traffic is least, that is, as a rule, in its earliest years; and that its expenses per unit of traffic diminish as its traffic, or in other words as its age, increases. He should know, therefore, that he cannot draw a fair comparison between any two lines in the same year, unless that year satisfies the paramount condition, that the quantity of traffic on the lines compared was during that year approximately the same; and that, therefore, it is wholly unreasonable to compare the Rajputana with the Great Indian Peninsula or Bombay and Baroda during a period when the goods traffic of the Great Indian Peninsula was six times, and that of the Bombay and Baroda three times, as great as, and when their passenger traffic was from 80 to 40 per cent. greater than that of, the Rajputana.

A still graver error on Mr. Carroll's part is his selection of the *gross* ton mileage, that is, the freight and dead weight moved together, as his basis of comparison of working cost, instead of the *net* ton mileage, that is to say, the freight moved only. He does not even call attention to the fact that he is using the gross ton mileage, for he calls it simply ton mileage, and it is probable that his readers generally have hitherto supposed him to mean what is usually meant by ton mileage, namely, the net or freight.

Mr. Carroll must be perfectly well aware that economy of railway management is not to be judged by the cost of the effort made, that is to say, the number and weight of trains run, but by the cost of the effect produced, that is to say, the freight carried; and that a large diminution may be effected in the cost per *gross* ton moved by simply increasing the dead weight, though, of course, the cost per *net* ton, or ton of freight, would be much increased thereby. He must be aware that loud complaints have been made against the enormous proportion of dead to live weight moved upon railways in India; that it is, in fact, the crying evil of railways generally, much worse, indeed, in England, than in India, and that to award the palm of merit to the line which shows the lowest cost

per *gross* ton mile is very possibly to give it to the line which least deserves it.

Mr. Carroll's basis in this respect is so utterly fallacious, that I shall not attempt to follow him through figures resting upon it. But I may point out that in Table I, (Working Expenses and Profits,) profits and the proportion which receipts bear to expenditure depend in a measure on the rates charged. This is not of much importance in the year Mr. Carroll has taken, but it is of very great importance in the years which I shall select for comparison.

Mr. Carroll's Tables II and III (Maintenance of Way and Locomotive) where based on the mile of railway maintained, and train mile, are not unfavourable even in 1877 to the Rajputana; where based on what he calls ton mileage, meaning thereby gross ton mileage, they are vitiated by the fallacy of the basis on which they are founded.

His Table IV (Carriage and Wagon) is favourable to the Rajputana so far as the Great Indian Peninsula is concerned; unfavourable so far as the Bombay and Baroda is concerned. Mr. Carroll gets over this by declaring the Great Indian Peninsula charge abnormally high. I might with equal reason declare the Bombay and Baroda abnormally low. But the carriage and wagon department is comparatively a small one, and the probability is that this department of the Rajputana was going through an experimental stage, which temporarily increased its cost. Moreover, the Government charges to Revenue many things which the Companies charge, I do not say improperly, to Capital.

As to Table V, (Working Expenses, Total,) the enormous variations between the two broad gauge lines in the details, point to differences of circumstances which vitiate the whole.

As to Table VI, (Weight of Trains,) the unit of traffic is not stated, and the Bombay and Baroda line goods load is put at 188·50 tons.

This must be an error. No Indian Railway has yet reached this average load. The true load was, I believe, 128·5 tons. The error is repeated in Table VIII.

Labour, however, is ill bestowed on figures based on thoroughly false assumptions, and I shall, therefore, now proceed to show that, taking fair bases of comparison, the metre gauge on the Rajputana line has already satisfied all that its promoters claimed for it, and that, though with more experience and larger traffic, better results may be looked for as

years go on, it shows in 1878 a far greater measure of success than either the Great Indian Peninsula or the Bombay and Baroda at a much later period of their existence, and with a consequently much larger traffic.

I have first to establish a fair basis of comparison in respect to time. Mr. Carroll cannot object to my taking the Rajputana at as late a period as possible, that is to say for the year 1878. The returns for that year have just been received, and show, as might be expected, a great improvement over 1877, the traffic being much larger, and the working expenses being almost exactly the same as in 1877.

In the next place, I claim a right, to which he cannot object, to compare the Rajputana with the Great Indian Peninsula and Bombay, Baroda and Central India at periods when the traffic upon these lines was about the same as on the Rajputana in 1878. To arrive, however, at such periods I must go back beyond the date from which I have the necessary materials for comparison. I am content, therefore, to accept for both the broad gauge lines, a year too favourable to them, namely, 1874. The traffic on both of them in that year, though much lower than in 1877, was still far ahead of the Rajputana. I can afford, however, to concede to Mr. Carroll this advantage, for, at nearly every point, the Rajputana in 1878 shows a clear superiority to both of them in 1874.

Lastly, I shall, of course, use the net ton mile as my standard of efficiency and economy.

The tables relating to 1874, prepared by me, and published by Mr. Danvers in his Report to the Secretary of State of the following year, have not only not been impugned, but their form has been adopted and continued in following years by the Great Indian Peninsula and other Companies. I am therefore justified in using them here as correct, and shall proceed to do so, adding to them other data derived from them, to which I desire to call attention. I should state that, in regard to the sums which I have put down as the capital expenditure on the three lines, the cost of the broad gauge lines is taken from Mr. Danvers' Report for 1874, and that of the narrow gauge from its last year's accounts, that I omit from the narrow gauge Capital the cost of land, because land is not included in the broad gauge Capital, and that I have converted rupees into sterling at 1s. 10d., that being the rate of conversion in the broad gauge accounts.

I make, then, the following comparison :—

CAPITAL.

Cost and Profit	Great Indian Peninsula, in 1874	Bombay, Baroda, and Central India, in 1874	Rajputana, in 1878
Average length open in year, ..	Miles 1,266	Miles 424	Miles 416½
(1). Capital cost to end of year named,	£ 28,084,484	£ 7,833,223	£ 2,660,000 (for 428½ miles).
(2). Cost per mile of line,	£ 18,240	£ 18,480	£ 6,215
(3). Net revenue required to pay 5 per cent. interest for mile, ..	£ 912	£ 924	£ 311
(4). Actual net revenue per mile earned in years taken,	£ 622	£ 590	£ 250
(5). Actual percentage on capital which was given thereby, ..	Per cent. 3·4	Per cent. 3·14	Per cent. 4
(6). Net revenue per mile which would have been earned on the traffic carried, if all three lines had charged Great Indian Peninsula average rates, ..	£ 622	£ 700	£ 536
(7). Percentage of profit on capital which would have been given thereby,	Per cent. 8·4	Per cent. 3·75	Per cent. 8·6

(6) and (7) assume, of course, that the quantity of traffic and the profit upon it would not have been affected by the increase of rates on the Bombay and Baroda, and the Rajputana.

Note.—Some expenditure has yet to be incurred on the Rajputana for fencing, &c., but, on the other hand, its cost was greatly enhanced by the permanent way materials, rolling stock, and plant generally having been purchased in England when such materials were at the highest prices ever known. This alone added at least £500 a mile to the cost of the Rajputana.

REVENUE.

A.

Passenger Traffic	Great Indian Peninsula, in 1874	Bombay, Baroda, and Central India, in 1874	Rajputana, in 1878
(8). Receipts from passenger traffic,	£ 438,544	£ 203,382	£ 75,457
(9). Passenger train miles run, ..	No 1,467,561	No 482,605	No 400,544
(10). Average passenger train mile receipts,	s. d. 5 11½	s. d. 8 5	s. d. 3 9½ (Note the average fares charged).

REVENUE—(continued.)

Passenger Traffic	Great Indian Peninsula, in 1874	Bombay, Baroda, and Central India, in 1874	Rajputana, in 1874
(11). Number of passengers carried one mile,	No 254,228,546	No 137,490,000	No 79,024,000
(12). Average sums received for carrying a passenger one mile, ..	d. ·414	d. ·355	d. ·227
(13). Average number of passengers in a train at one time, ..	No 173	No 285	No 197
(14). Average number of passenger trains per diem each way, supposing each train to traverse the whole line open, ..	No 1·59	No 1·56	No 1·32
(15). Average number of passengers passing over each mile of line daily (both ways),	No 550	No 888	No 520
(16). Number of passenger vehicles run one mile in year, ..	No 20,071,892	No 4,234,639	No 7,610,336
(17). Average number of passenger vehicles in a passenger train, ..	No 13·7	No 8·8	No 19
(18). Average number of passengers in each vehicle, average capacity of carriages,	No 12·66 say 50 ?	No 32·5 say 70 ?	No 10·4 say 30 ?
(19). Total working expenses for both goods and passengers, deducting special and miscellaneous receipts from them,	£ 1,020,398	£ 257,767	£ 160,790
(20). Average working expenditure per mile of open line, ..	£ 806	£ 608	£ 386
(21). Average cost of running a train one mile, passenger and goods miles assumed to cost the same,	s. d. 5 2½	s. d. 5 3	s. d. 3 2½
(22). Average cost of carrying a passenger vehicle with its load one mile,	d. 4·55	d. 7·16	d. 2·07
(23). Average cost per gross ton mile moved, taking broad gauge carriages to weigh 8 tons, narrow 4 tons, and passengers 12 to ton (approximate), ..	d. ·5	d. ·65	d. ·4
(24). Average cost of carrying a passenger one mile,	d. ·36	d. ·221	d. ·197
(25). Average weight of passenger trains (approximate), ..	Tons 123	Tons 94	Tons 90
(26). Proportion of line weight of passenger trains to total load (approximate),	13 100	25 100	16·5 100

Note.—That the cost of carrying passenger traffic, gross and net, is lowest on the Rajputana, and that the proportion of net to gross passenger load, though best on the Bombay, Baroda, and Central India, is far worse on the Great Indian Peninsula than on the Rajputana. The superiority of the Bombay, Baroda and Central India in this respect is probably owing to the double storied carriages in use on that line.

B.

Goods Traffic	Great Indian Peninsula, in 1874	Bombay, Baroda, and Central India, in 1874	Rajputana, in 1878
Average length open in year, ..	Miles 1,266	Miles 424	Miles 416½
(1). Receipts from goods traffic, ..	£ 1,869,088	£ 304,288	£ 188,959
(2). Goods train miles run, ..	No 2,457,093	No 499,501	No 595,086
(3). Average goods train mile receipts,	s. d. 11 1½	s. d. 12 2	s. d. 6 4½
			(Note the average rates charged).
(4). Tons of goods carried one mile,	Tons 201,576,000	Tons 46,025,543	Tons 36,500,978
(5). Average sum received for carrying one ton one mile, ..	d. 1·63	d. 1·586	d. 1·24
(6). Average number of tons in a goods train at one time, ..	Tons 82	Tons 92	Tons 61·3
(7). Average number of goods trains per diem each way, supposing each train to run over the whole line open, ..	No 2·66	No 1·61	No 1·95
(8). Average number of tons of goods passing over each mile of line daily (both ways), ..	Tons 437	Tons 297	Tons 240
(9). Number of goods vehicles run one mile in the year, ..	No 58,244,333	No 15,863,683	No 13,538,206
(10). Average number of goods vehicles in a goods train, ..	23·7	30·75	22·75
(11). Average number of tons in each goods vehicle, ..	Tons 3·46	Tons 3	Tons 2·67
Average capacity of wagons, ..	say 7 tons	say 8 tons	say 5 tons
For working expenses, total, and per mile, <i>see</i> Passenger No. 19 and 20.			
(12). Average cost of carrying a goods vehicle with its load one mile, ..	d. 2·64	d. 2·05	d. 1·68
(13). Approximate average cost of carrying one ton gross, that is, wagon and load together, one mile. (In this I take average weight of broad gauge wagon stock at 5½ tons, of narrow gauge at 3 tons), ..	d. ·29	d. ·23	d. ·3
(14). Average cost of carrying one ton of goods freight one mile, ..	d. ·763	d. ·685	d. ·63
(15). Average weight of goods train approximate, ..	Tons 218	Tons 271	Tons 129
(16). Approximate proportion of live load to total weight of train in goods trains, ..	3 s 100	34 100	48 100

Note.—That while the cost per *gross* ton mile is highest on the Rajputana, the cost per *net* ton mile is lowest on that line, which shows the fallacy of a *gross* ton mile basis; and the proportion of net to gross load is much the best on the Rajputana.

To these tables let me add that, in regard to gradients, omitting the Ghauts on the Great Indian Peninsula, which affect but a small portion of it, that line is not materially worse than the Rajputana, there being, I believe, on the Rajputana upwards of 70 miles out of 420 on an incline of 1 in 150 or less, while the Bombay and Baroda is practically a level line; that the water on the Rajputana is exceptionally bad, and has a most injurious effect on the development of locomotive power and the durability of locomotive boilers, and that fuel, as Mr. Carroll admits, is dearer on the Rajputana than on either of the broad gauge lines.

I confess I was not prepared to find the Rajputana compare so favourably with lines three times its age, like the Great Indian Peninsula and the Bombay and Baroda, for it must be remembered that nearly every portion of the structure and rolling stock of the narrow gauge lines involves a departure from established patterns and experience, and that some mistakes and consequent waste were therefore inevitable, and have to be corrected at the cost of revenue.

But whatever be its present shortcomings, it exhibits a railway equal, for all the purposes it is intended to serve, to either of the Bombay lines, yet built at little more than one-third their cost per mile; working at lower cost, in spite of a much smaller traffic, and more unfavourable mechanical conditions; and paying a higher dividend than either, although its rates are so low, that had its traffic been carried at the charges levied by the Great Indian Peninsula, its profits, assuming its traffic not to have been diminished thereby, would have been double what they were.

That there is room for improvement may be conceded. But there is no reason to suppose that we shall not see in the Rajputana during the next four years the same advance in all points that we have seen in other Indian lines during the last four years. The train loads, though they were actually in 1878 in excess of the Great Indian Peninsula in 1874 in passengers, are still less than I think they ought to be both in goods and passengers; the amount of work done by the Rajputana wagon stock in 1878 was little more than one-third that done in the same year by the East Indian, amounting to only 6,000 ton miles per annum per ton of capacity, against about 16,000 ton miles on the East Indian; and the

average weight of the Rajputana trains shows that the loads put behind its locomotives are less than they could easily carry. The inference is that the large indents lately sent in for more stock are in the main unnecessary, unless the increase which has taken place during the present year be, what I do not believe it is, more than can be met by good management accompanied by fair co-operation on the part of those who provide the traffic.

On the general question of the capacity of the metre gauge for traffic, results so far show, without doubt, whether we look at the Rajputana or the South Indian, that its practical capacity is not likely to be approached by the traffic brought upon it.

The Rajputana traffic in 1878 amounted to 526 passengers and 247 tons of goods passing over each mile each day on the average; and this traffic was carried in little more than three trains. Even assuming that the work per train was as much as could be expected, we know from the experience of the Tirhoot line during the Bengal famine, and from that also of the broad gauge lines, that at least twelve trains a day may be run each way on a single line. This would allow of a traffic of *at least* 1,500 passenger, and 1,200 tons of goods per mile per diem, a traffic which no line in India, except the East Indian Railway, has yet carried, unless in time of famine.

It is inconceivable that the local traffic of the Rajputana should approach these figures. The only prospect of its obtaining any large fraction of such a traffic must come from North-West Province traffic passing over it to Bombay. That this will happen to some extent is, no doubt, probable, but, looking to the competing routes to Kurrachee, to Calcutta, and to Bombay by Holkar's line and Jubbulpore, the time must be distant, indeed, when the carrying powers of *the road* will be seriously tested.

24th July 1879.

P.S.—Since the foregoing was written, the accounts of the Great Indian Peninsula and Bombay, Baroda and Central Railway Companies for 1878 have been completed and issued, and I have had an opportunity of comparing them with those of the Rajputana for the same year. The working expenses per train mile on the Great Indian Peninsula for 1878 are 8s. 9d.; on the Bombay and Baroda 4s. 9d.; on the Rajputana 8s. 2½d. The working expenses per passenger mile are the same on the

Bombay and Baroda and the Rajputana, *viz.*, $\cdot 197d.$, but greater on the Great Indian Peninsula than on either, namely, $\cdot 209d.$ The working expenses per ton mile are greatest on the Rajputana, $\cdot 63d.$ against $\cdot 51d.$ on the Great Indian Peninsula, and $\cdot 45d.$ on the Bombay and Baroda. But then the traffic on the Rajputana was much smaller than on either of the broad gauge lines, for the daily tonnage passing over each mile of the Great Indian Peninsula was 902 tons, over the Bombay and Baroda 502 tons, over the Rajputana only 240 tons, and the daily number of passengers passing over each mile on the three lines was 768, 923, and 520 respectively.

By working expenses in the above figures, I mean the cost of maintaining the lines and conducting the traffic upon them only. To arrive at the actual cost of transport upon them, we should add to the working expenses, fair interest on the cost of constructing them. The superior economy of the narrow gauge would then be very apparent.

But the fact is, that gauge has nothing to do with the cost of transport, so long as the power of the machine is proportioned to the work to be done, a narrow gauge being probably best suited to a small traffic, and a broad gauge to a large traffic.

Assuming equally good and permanent materials to be supplied in each case, working expenses depend chiefly on the quantity of the traffic carried, on its management, and on physical conditions in regard to levels, coal, water, &c.

If we take, for instance, the East Indian, the Madras, and the Oudh and Rohilkund broad gauge lines, and the South Indian and Rajputana narrow gauge lines, in the year 1878, we find the following:—

	BROAD GAUGE			NARROW GAUGE	
	East Indian	Madras	Oudh and Rohilkund	South Indian	Rajputana
Length of line open,	Miles 1,504	Miles 858	Miles 544	Miles 611	Miles 416½
Average number of passengers in trains at one time,	No 229	No 205	No 316	No 290	No 197
Average number of passengers passing over each mile daily, ..	1,140	536	796	880	520
Cost of carrying a passenger one mile,	$\cdot 15$	$\cdot 234$	$\cdot 1059$	$\cdot 1327$	$\cdot 197$

	BROAD GAUGE			NARROW GAUGE	
	East Indian	Madras	Oudh and Rohilkund	South Indian	Rajputana
Number of tons of goods in trains at one time,	Tons 130 8	Tons 53·7	Tons 92	Tons 50	Tons 61·3
Number of tons of goods passing over each mile daily,	1,280 <i>d.</i>	229 5 <i>d.</i>	400 <i>d.</i>	120 <i>d.</i>	240 <i>d.</i>
Cost of carrying one ton one mile,	·26	·895	·366	·77	·63
Cost of running a train (passenger or goods) one mile,	<i>s.</i> <i>d.</i> 2 10½	<i>s.</i> <i>d.</i> 4 0½	<i>s.</i> <i>d.</i> 2 9½	<i>s.</i> <i>d.</i> 3 2½	<i>s.</i> <i>d.</i> 3 2½

These figures, it must be remembered, assume a passenger and a goods train mile to cost the same. An error in this assumption, however serious, would not affect the general result, and the difference between the two is, at any rate, small.

The average loads per train on the South Indian are also, to a certain extent assumed, in default of the requisite materials to determine them accurately. If the goods train loads are assumed too high, those of the passenger trains are too low, and *vice versa*. And I should notice that the Oudh and Rohilkund cost per train mile is somewhat abnormally low, owing to the large receipts of that Company in 1879 from wagons hired to, or running on, other lines, which receipts go, in my method of stating the costs, in reduction of working expenses.

Now, in these figures, if we compare the Rajputana narrow gauge with the Madras broad gauge, two lines having almost exactly the same quantity of traffic, and somewhat similar physical conditions, we find the narrow gauge beating the broad in goods train loads, and nearly equal to it in passengers, and carrying its traffic at far smaller cost per passenger mile, per ton mile, and per train mile. The South Indian narrow gauge line shows equally well beside the Madras, but both the narrow gauge lines show ill beside the broad gauge Oudh and Rohilkund and the East Indian. If this were due to gauge they would look equally ill beside the Madras. The cause is clearly something independent of gauge, quantity of traffic being evidently very important.

With more traffic and experience I have no doubt that the Rajputana will show, as nearly all other Indian lines have done, a constant improvement, and also that its working cost is independent of gauge, unless in-

deed its traffic reaches to something like that of the East Indian. When that time comes the financial position of the line will be such that we may view a change, if change be thought desirable, with equanimity. I am only afraid that that time will never come.

No. CCCXXVII.

REPORT ON THE IRON ORE AND COAL
FROM THE CHANDA DISTRICT
OF THE CENTRAL PROVINCES OF INDIA.

By MR. WILLIAM HACKNEY.

To—GENERAL HYDE, R.E.

SIR,—In accordance with your request, I have carefully studied the question how iron or steel may be best made from the minerals of the Chánda district of the Central Provinces of India; and I have now the honour to report on the matter as follows:—

I.—*Character of the Chánda Minerals.*

The only colliery at work in the district is, I understand, that at Warora.

An average sample, analyzed by Mr. E. Riley, of the Warora coal sent to England by the steam ship “Burmese” was found to contain—

Moisture, driven off at 212° Fahr.,	..	..	..	..	11.00
Volatile carbonaceous matter,	..	..	..	..	81.64
Fixed carbon,	..	..	..	..	43.42
Ash,	..	..	..	..	13.94
					<hr/> 100.00

Sulphur, per cent.,	..	..	..	..	..	1.15
---------------------	----	----	----	----	----	------

Or, in other words, when heated in a close vessel, the undried coal yielded 57.36 per cent. of coke, containing—

Carbon,	..	..	..	..	..	75.7
Ash,	..	..	..	..	..	24.3
						<hr/> 100.0

and dried coal would yield 64.4 per cent. of the same.