Professional Papers on Indian Engineering
Vol. IX
(1880)

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PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING.

[SECOND SERIES.]

EDITED BY

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VOL. IX.

ROORKEE:

PRINTED AND PUBLISHED AT THE THOMASON COLLEGE PRESS.

1880.

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

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[SECOND SERIES].

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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 1½ feet. The mean velocity of river in flood is 3 miles an hour, decreasing to ¾ 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 1½ 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, 3,800 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 2½ 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 superstructive parapet, to be composed of concrete, and continuously built, from 3 to 6 feet wide, and from 2½ 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 5½ 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, 16½ 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′ × 70′ area, founded on 400 piles at intervals of 8 feet, connected by 5″ × 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 ¼-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 7½ 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 ¼-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 7½ 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 2½ to $\frac{1}{30}$-inch in diameter. The sand was moderately coarse and sharp-grained; average diameter of grains $\frac{1}{40}$-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)

Fig. 2.

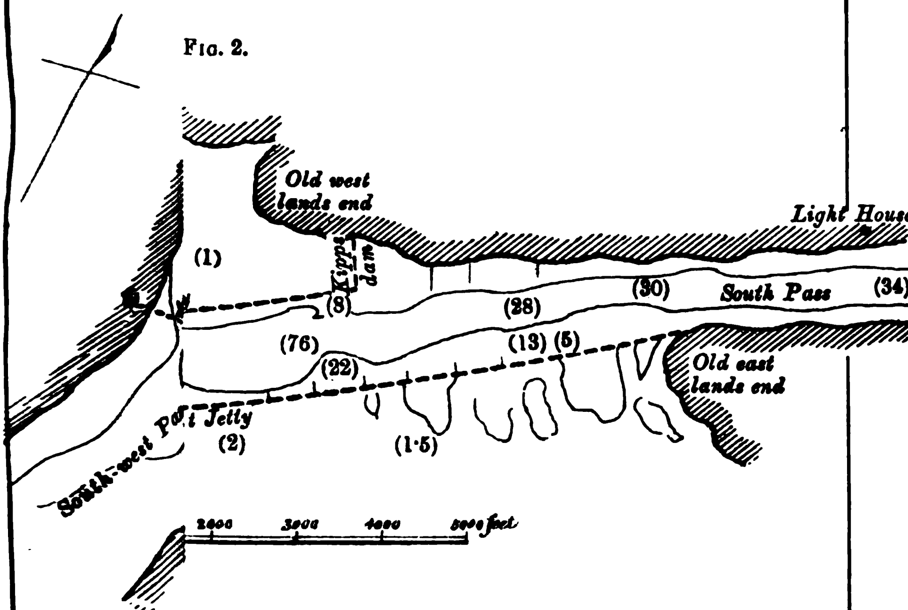
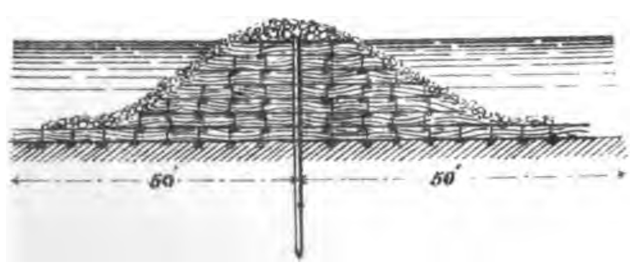
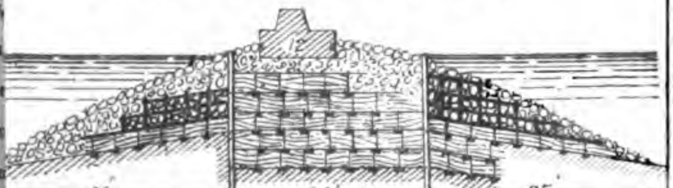


Fig. 4.
SECTION JETTIES AS ORIGINALLY PROPOSED.



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

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



...o 1 inch (Fig. 3 to 6).
20 30 40 feet

Litho. T. C. Press, R... Thos. D. Bona, Sup.

Fig.

Fig. 2.

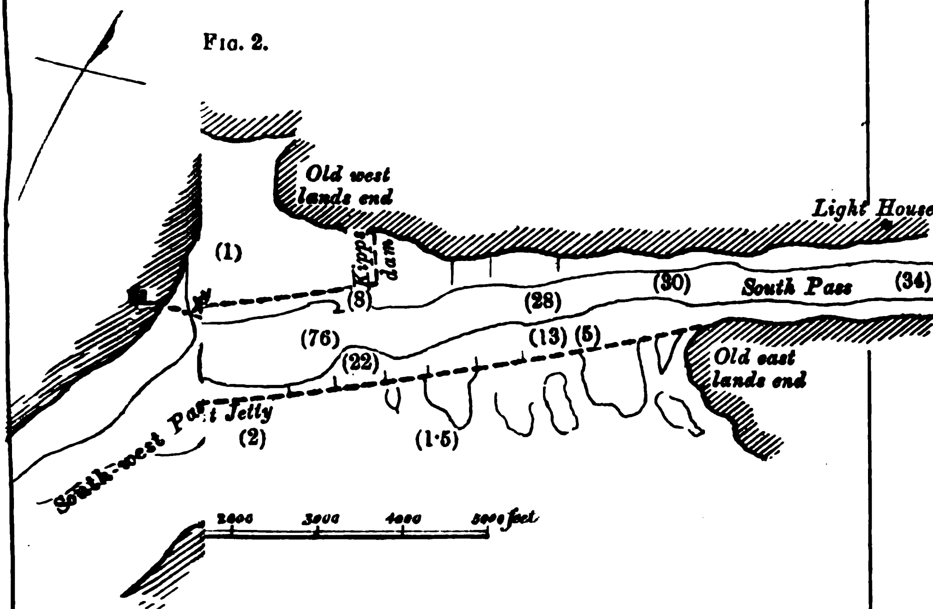


Fig. 4.
SECTION JETTIES AS ORIGINALLY PROPOSED.

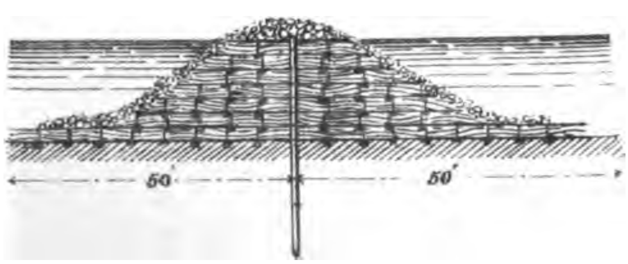


Fig. 6.
SECTION 11,800 FEET FROM EAST POINT.

…o 1 inch (Fig. 3 to 6).
20 30 40 feet

No	Name of …
1	East Dyk…
2	Dam, 1,
3	Lighthous…
4	Island Dy…
5	Lighthous…
6	South-We…
7	West Dyk…
8	Island Dam…
9	Island Dyk…
10	Pass a L'O…
11	Upper Da…
12	Island Dyk…

Litho. T. O. Press, R…
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 A*r* 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 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 AC*a* = ACB, or adding ADC, triangle AD*a* = quadrilateral ABCD, and again side ED produced to meet line from *a* parallel to diagonal AD in *b* gives triangle AD*b* = triangle AD*a* 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 D*h* the half of D*b*. Reciprocate $g''h$, *i.e.*, mark off length *h*D 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 E*l*, the half of E*c*. 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.

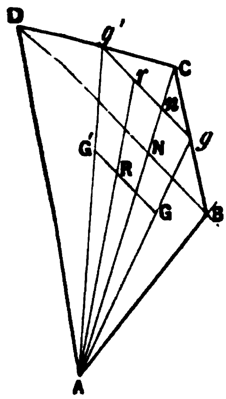


Fig. 2.

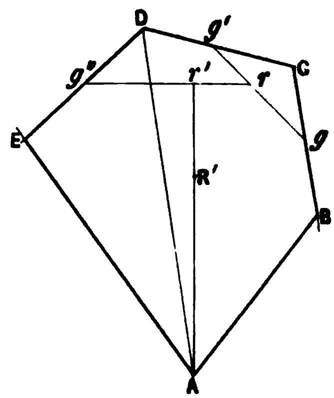


Fig. 3.

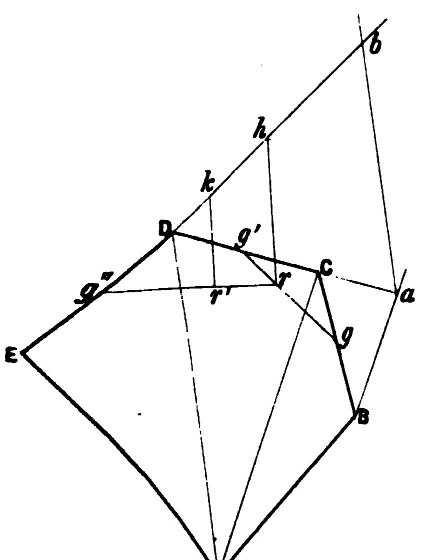
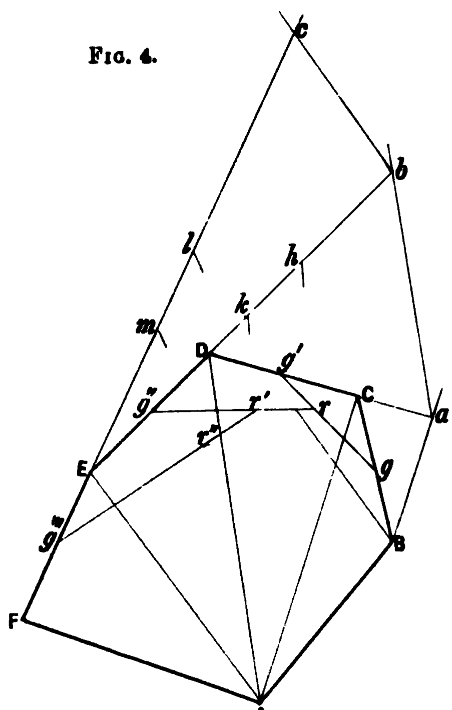


Fig. 4.



Litho. T. C. Press, Roorkee. THOS. D. BONA, Supdt.

No. CCCXX.

INSPECTION NOTES—PANJAB RAILWAYS.

By Col. J. G. Medley, R.E., *Consulting Engineer for Railways.*

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

Dated Lahore, 18th 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 nallahs (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-feet 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 $\frac{3}{8}$".
" " N. " " $\frac{3}{8}$".

Recovery complete.
At speed S. girders, D. $\frac{3}{4}''$; O. $\frac{1}{4}''$.
„ N. „ D. $\frac{5}{8}''$; O. $\frac{1}{8}''$.

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

---

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

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

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(6). Arál bridge, 8 40-feet girders—
D. $\frac{3}{8}''$; O 0.

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

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

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(9). Bridge between Manjhand and Gopang—
12-metre opening: D. $\frac{1}{4}''$; O. $\frac{1}{8}''$.

---

(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 porterage.

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	To be erected, of which about 20 only are being erected, and may be ready after three months. No news as to when the rest may be ready.
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 $1\frac{5}{16}$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 trolly, 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 $\frac{1}{10}$th of an inch, fixed laterally to the lower flange. The result of several observations showed a mean oscillation of $\frac{3}{10}$ths of an inch only, the girders observed by Colonel Bonus showing $\frac{2}{10}$ths. The deflections under the fast train, as shown by diagram, were 1·4 and 1·3 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 asphalte; 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 Naurangawáli, 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 $1\frac{3}{8}$th 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 accessaries, 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.

Testing Sutlej Bridge Girders, May 22nd and 23rd, 1876.

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.	Lateral oscillation.	
Mooltan end.															
A—B,	...	girders will be reported afterwards; it is an average.		$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$\frac{1}{32}$	...	$1\frac{3}{8}$	$1\frac{5}{16}$	1·4	1·4	·8	Col. Medley.
B—C,	...			$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{1}{16}$	$\frac{1}{32}$	$1\frac{1}{4}$	$1\frac{5}{16}$	not taken.	ditto.	ditto.	Col. Bonus.
C—D,	...			$1\frac{9}{32}$	$1\frac{5}{32}$	$1\frac{9}{32}$	$1\frac{5}{32}$	$\frac{1}{16}$	$\frac{1}{32}$	$1\frac{5}{16}$	$1\frac{5}{16}$				
D—E,	...			$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$\frac{1}{32}$	$\frac{1}{32}$	$1\frac{1}{4}$	$1\frac{1}{4}$				
E—F,	...			$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{1}{16}$	...	$1\frac{5}{16}$	$1\frac{1}{4}$				
F—G,	...			$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{1}{16}$	...	$1\frac{3}{16}$	$1\frac{1}{4}$				
G—H,	...			$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{1}{16}$	...	$1\frac{1}{4}$	$1\frac{5}{16}$				
H—J,	...			$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$\frac{1}{16}$	...	$1\frac{1}{4}$	$1\frac{1}{4}$				

J—K, ...	Amount of cambers given to the several about 4″ on	$1\frac{1}{8}$	$1\frac{3}{32}$	$1\frac{1}{8}$	$1\frac{3}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$1\frac{3}{8}$	$1\frac{3}{8}$	Others	Ditto.	Ditto.	Col. Medley.
K—L, ...		$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{1}{4}$				
L—M, ...		$1\frac{3}{32}$	$1\frac{3}{32}$	$1\frac{1}{8}$	$1\frac{3}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{1}{4}$				
M—N, ...		$1\frac{1}{8}$	$1\frac{5}{32}$	$1\frac{3}{16}$	$1\frac{5}{32}$	$\frac{1}{16}$	...	$1\frac{3}{8}$	$1\frac{3}{8}$				
N—O, ...		$1\frac{3}{32}$	$1\frac{1}{8}$	$1\frac{3}{32}$	$1\frac{1}{8}$	...	...	$1\frac{1}{4}$	$1\frac{1}{4}$				
O—P, ...		$1\frac{3}{16}$	$1\frac{7}{32}$	$1\frac{3}{16}$	$1\frac{7}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$1\frac{5}{16}$	$1\frac{1}{4}$				
P—Q, ...		$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{7}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$1\frac{3}{8}$	$1\frac{3}{8}$	1·8	1·8	·2	Col. Bonus.
Q—R, ...		$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{5}{32}$	$1\frac{5}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$1\frac{1}{4}$	$1\frac{5}{16}$	1·3	1·3	·2	
Bahawalpur end.													

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, 22nd 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 8½ 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 10½ 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 transhipment 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 $\frac{1}{9}$ pie per maund per mile, or about $\frac{3}{8}d.$ 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 Ferozepore; 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 Rájpura (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. 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 Baisákhi festival at Amritsar, and the Pihowah Fair (near Thánesar) both occur in the spring, and the Diwáli 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-feet 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 Hamíra 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-feet 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 8½ feet apart in the clear. The pier foundations are 4 feet below the surface (1½ feet concrete and 2½ 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.

Hambowál.—Four 60-feet 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.

Ramídi Nallah.—Four 60-feet 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 Ramídi bridges having been shifted inwards. This makes it all the more necessary that No. 2 gap should have its full length.

Ramídi.—Three 110-feet 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 Ramídi bridge, and I hope this will now be given. It will *all* be wanted here.

West Beyn.—Four 110-feet girders = 404 feet; pier wells are 81 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 Hamíra.—Both thrown into one; four 60 feet girders and two 54 feet girders. Wells will be ready for hearting by 20th May.

The old Hamíra 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-feet girder flood openings connecting the bridge with a 40-feet 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—

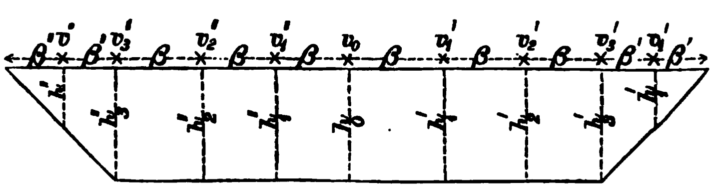
$$D = \tfrac{3}{10}\beta \{h_3'' v_3'' + h_1'' v_1'' + h_0 v_0 + h_1' v_1' + h_3' v_3' + 5(h_2'' v_2'' + h_0 v_0 + h_2' v_2')\}$$

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

$$D_1 = \tfrac{1}{3}\beta' (h_3' v_3' + 4 h' v')$$

$$D_2 = \tfrac{1}{3}\beta'' (h_3'' v_3'' + 4 h'' v'')$$

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-

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. River.		GAUGE READINGS. Canal.		HEAD ON SLUICE.			SQUARE ROOTS OF HEADS.		Observed discharge.	HEAD SLUICE.		VALUES OF x IN FORMULA $v = x\sqrt{H}$	
	Before experiments.	After experiments.	Before experiments.	After experiments.	Observed.	Correction to be added.	Corrected head.	Observed head.	Corrected head.		Area of ventage open.	Velocity through vents due to observed discharge.	Due to observed head.	Due to corrected head.
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	963	175	5·50	9·1	8·3
„ 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	·26	·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	4·38	8·1	7·4
Averages,	..	..	..	..	..	..	·31	..	·58	..	..	4·78	9·48	8·5

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 cut-waters 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_3 be the velocity at 3 inches from the wall, v_6 that at 6 inches, and v_{12} that at 12 inches, $v_3 : v_6 : v_{12}$. At the surface this proportion is very nearly true on both sides of the vent. For the depths of 6½ and 7⅓ 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—

$$\left.\begin{aligned} &1{\cdot}91 \times {\cdot}5 = 0{\cdot}95 \\ &\frac{2{\cdot}15 + 2{\cdot}37}{2} \times {\cdot}5 = 1{\cdot}13 \\ &\frac{2{\cdot}37 + 3{\cdot}22}{2} \times 1{\cdot}5 = 4{\cdot}19 \\ &\frac{3{\cdot}22 + 3{\cdot}40}{2} \times 1{\cdot}5 = 4{\cdot}97 \\ &\frac{3{\cdot}40 + 3{\cdot}03}{2} \times {\cdot}5 = 3{\cdot}21 \\ &2{\cdot}83 \times {\cdot}5 = 1{\cdot}42 \end{aligned}\right\} \div 5$$

v at surface $= 3{\cdot}17$ feet per second.

At 1·0 feet below surface—

$$\left.\begin{aligned} &1{\cdot}75 \times {\cdot}5 = 0{\cdot}87 \\ &\frac{1{\cdot}91 + 2{\cdot}08}{2} \times {\cdot}5 = 1{\cdot}00 \\ &\frac{2{\cdot}08 + 3{\cdot}45}{2} \times 1{\cdot}5 = 4{\cdot}14 \\ &\frac{3{\cdot}45 + 2{\cdot}77}{2} \times 1{\cdot}5 = 4{\cdot}67 \\ &\frac{2{\cdot}77 + 2{\cdot}42}{2} \times {\cdot}5 = 1{\cdot}30 \\ &2{\cdot}17 \times {\cdot}5 = 1{\cdot}08 \end{aligned}\right\} \div 5$$

v at 1·0 below surface $= 2{\cdot}61$ feet per second.

At 3·0 feet below surface—

$$\left.\begin{array}{l} 2{\cdot}66 \quad \times \ {\cdot}5 = 1{\cdot}33 \\ \frac{3{\cdot}63 + 4{\cdot}09}{2} \times \ {\cdot}5 = 1{\cdot}98 \\ \frac{4{\cdot}09 + 4{\cdot}34}{2} \times 1{\cdot}5 = 6{\cdot}32 \\ \frac{4{\cdot}34 + 4{\cdot}50}{2} \times 1{\cdot}5 = 6{\cdot}63 \\ \frac{4{\cdot}50 + 3{\cdot}63}{2} \times \ {\cdot}5 = 2{\cdot}03 \\ 2{\cdot}42 \quad \times \ {\cdot}5 = 1{\cdot}21 \end{array}\right\} \div 5$$

v at 3 feet below surface = 3·89 feet per second.

5·0 feet below the surface—

$$\left.\begin{array}{l} 3{\cdot}2 \quad \times \ {\cdot}5 = 1{\cdot}60 \\ \frac{3{\cdot}36 + 3{\cdot}52}{2} \times \ {\cdot}5 = 1{\cdot}72 \\ \frac{3{\cdot}52 + 4{\cdot}46}{2} \times 1{\cdot}5 = 5{\cdot}99 \\ \frac{4{\cdot}46 + 4{\cdot}63}{2} \times 1{\cdot}5 = 6{\cdot}81 \\ \frac{4{\cdot}63 + 4{\cdot}04}{2} \times \ {\cdot}5 = 2{\cdot}17 \\ 3{\cdot}52 \quad \times \ {\cdot}5 = 1{\cdot}76 \end{array}\right\} \div 5$$

v at 5·0 below surface = 4·01 feet per second.

6·5 feet below surface—

$$\left.\begin{array}{l} \frac{2{\cdot}67 + 4{\cdot}12}{2} \times 2{\cdot}5 = 8{\cdot}49 \\ \frac{4{\cdot}12 + 3{\cdot}00}{2} \times 2{\cdot}5 = 8{\cdot}90 \end{array}\right\} \div 5$$

v at 6·5 below surface = 3·48 feet per second.

At bottom 7·36 below surface—

$$\left.\begin{array}{l} \frac{1{\cdot}76 + 2{\cdot}71}{2} \times 2{\cdot}5 = 5{\cdot}59 \\ \frac{2{\cdot}71 + 1{\cdot}97}{2} \times 2{\cdot}5 = 5{\cdot}85 \end{array}\right\} \div 5$$

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:—

$$\left.\begin{array}{l}
\frac{3{\cdot}17 + 2{\cdot}61}{2} \times 1{\cdot}0 = 2{\cdot}89 \\
\frac{2{\cdot}61 + 3{\cdot}89}{2} \times 2{\cdot}0 = 6{\cdot}50 \\
\frac{3{\cdot}89 + 4{\cdot}01}{2} \times 2{\cdot}0 = 7{\cdot}90 \\
\frac{4{\cdot}01 + 3{\cdot}48}{2} \times 1{\cdot}5 = 5{\cdot}61 \\
\frac{3{\cdot}48 + 2{\cdot}49}{2} \times {\cdot}86 = 2{\cdot}56
\end{array}\right\} \div 7{\cdot}36$$

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

$$3{\cdot}46 \times \frac{7{\cdot}36}{7} = 3{\cdot}63 \text{ feet per second.}$$

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

$$\left.\begin{array}{l}
\frac{3{\cdot}22 + 3{\cdot}45}{2} \times 1 = 3{\cdot}33 \\
\frac{3{\cdot}45 + 4{\cdot}34}{2} \times 2 = 7{\cdot}79 \\
\frac{4{\cdot}34 + 4{\cdot}46}{2} \times 2 = 8{\cdot}80 \\
\frac{4{\cdot}46 + 4{\cdot}12}{2} \times 1{\cdot}5 = 6{\cdot}43 \\
\frac{4{\cdot}12 + 2{\cdot}71}{2} \times {\cdot}86 = 2{\cdot}94
\end{array}\right\} \div 7{\cdot}36$$

v in central plane = 3·98 feet per second; but the mean velocity for the whole section = 3·46 feet per second—

$$\frac{3{\cdot}46}{3{\cdot}98} = {\cdot}87.$$

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 × ·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	6·34/6·34	2·28
	5·0	2·65	} 2·17	1·34	2·90				
	bottom (6·34)	*1·70							
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	7·36/7·00	3·82
	5·0	4·37	} 3·64	2·36	8·59				
	bottom (7·36)	*2·91							
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							
	5·0	3·50				3·64	3·17	6·6/6·6	3·17
	6·0	3·78	} 3·53	0·6	2·12				
	bottom (6·6)	*3·28							
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	7·5/7	4·02
	4·0	5·29							
	5·0	5·32							
	6·0	5·00	} 4·15	1·5	6·22				
	bottom (7·5)	*3·30							
September 17th.	Surface (0)	*3·80	} 4·13	2·0	8·26				
	2·0	4·47							
	3·0	6·35							
	4·0	6·74	6·17	4·0	24·68	5·40	4·69	8·0/7·0	5·36
	5·0	6·86							
	6·0	6·45	} 5·16	2·0	10·32				
	bottom (8·0)	*3·87							
Sept. 21st.	Surface (0)	3·68	} 3·88	1·0	3·88				
	1·0	4·09							
	3·0	4·75				4·35	3·79	7·0/7·0	3·79
	5·0	4·86	4·26	6·0	25·56				
	bottom (7·0)	3·33							

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 $\frac{\cdot 08 \times \text{calculated discharge}}{1000}$, 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. River. At beginning.	Gauge Readings. River. At end.	Gauge Readings. Canal. At beginning.	Gauge Readings. Canal. At end.	Mean Head on Sluice. Observed.	Mean Head on Sluice. Correction to be added.	Mean Head on Sluice. Corrected head.	Square Roots of Heads. Observed head.	Square Roots of Heads. Corrected head.	Mean velocity observed by current meter.	Discharge of canal due to velocity through sluice.	Values of x in formula $v = x\sqrt{H}$. Due to observed head.	Values of x in formula $v = x\sqrt{H}$. Due to corrected head.
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.*

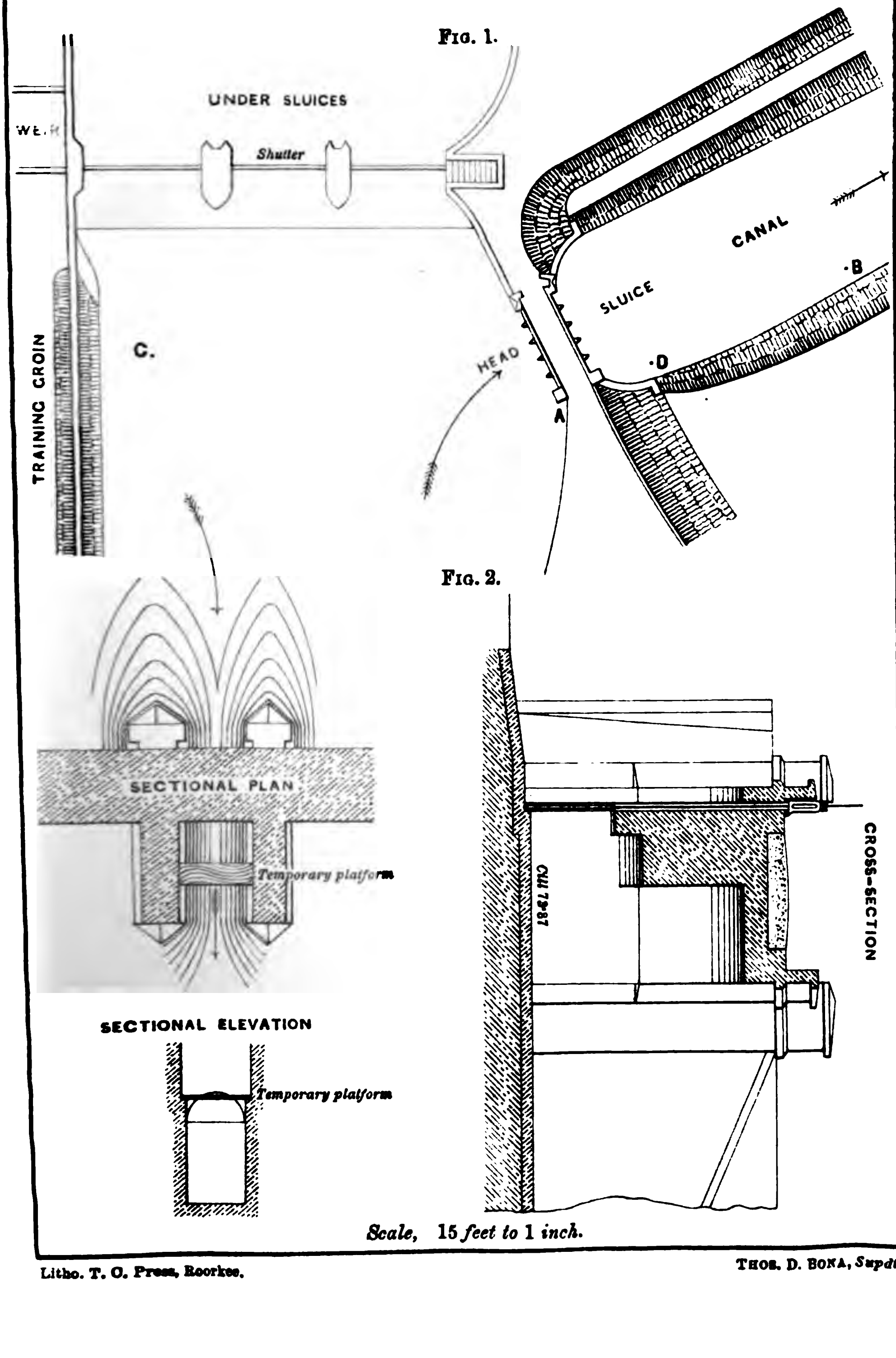
See para. 7.—3°. The "heads" of water are so small that their accurate determination is difficult. The two gauges marked C and B in *Plate* I., would have given *probably* the better values for use in the formula $v = x\sqrt{H}$; but the uncertainty of applying a conjectural correction of ·08 to heads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

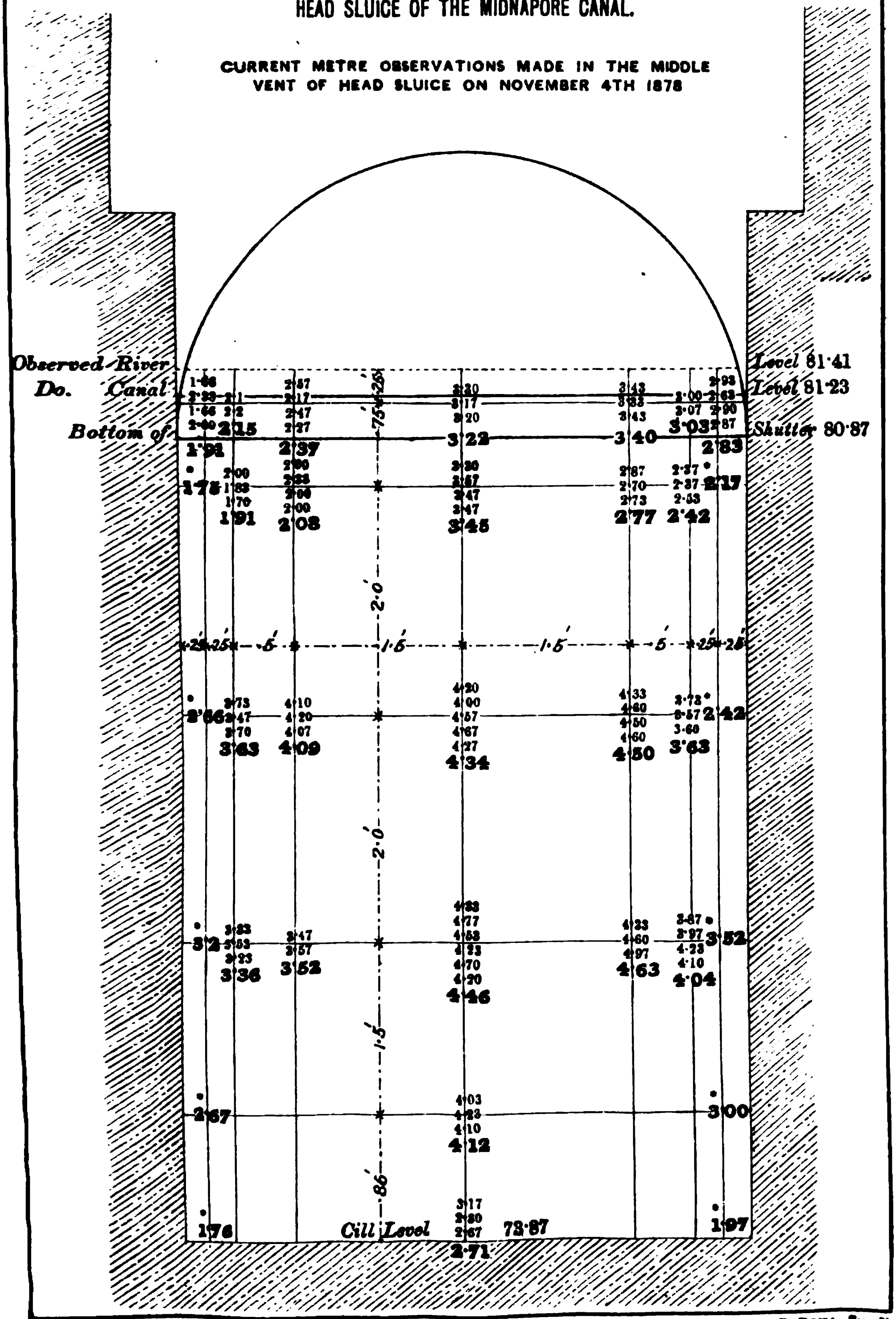


Scale,* 15 *feet to* 1 *inch.

Litho. T. O. Press, Roorkee. THOS. D. BONA, *Supdt.*

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



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No. CCCXXII.

ON THE ACTION OF FALLING WATER.

[*Vide* Plates I.—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* 13*th 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′ × 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

$$d = 1{\cdot}5\,\sqrt{h}\,;\ \sqrt[3]{h'}$$

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 $69 \times 62{\cdot}5 = 4{,}312$ 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—

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

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

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

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

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

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

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

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* 30*th 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. 462W 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 rule[1] for resistance produced by a moving fluid on a fixed obstacle, and both the proof and rule have been acknowledged to be so defective, as to be omitted from the last edition of the Cambridge Text-book on Hydromechanics (Besant's).

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

[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.

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 same effect[2] either in attrition or in blowing out, which occasionally occurs. The motion of viscous fluids has not yet been subjected, from the inherent difficulty of the investigation, to mathematical analysis. But there are several reasons why Mr. Beresford's rule seems to me to give certainly much too small a pressure. 1*st*, 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 account,[3] although he states that the water rebounds, and endeavours to explain why some particles of the

[2] On the contrary, I think a much greater effect in blowing out; for I know of no case in which a mass of masonry corresponding in weight per unit of horizontal area to the possible hydrostatic pressure, has been blown up by water falling with a velocity due to this pressure.

J. S. B.

[3] Mr. Eliot has again apparently misunderstood me. He here refers to the total action during impact, and

water rise to a much greater height than the top of the fall.

Again, Mr. Beresford leaves out another important element, the area over which the water meets the bottom after its descent; *Fig.* 2 and *Fig.* 6 both show (and show correctly) that the water in falling (or the stream leaves) will be approximately parabolic, and that under the peculiar circumstances, increasing velocity during descent, and very slight differences in the height of the fall, the thickness of the falling water in the horizontal direction will diminish. The action and rate of pressure, it is evident, will depend very considerably upon the area[4] on which the water falls: it would be quite easy to calculate the amount of the contraction (from the parabolic paths described). It is very evident that the increased rate of pressure due from this action may be very considerable.[5]

Without enumerating one or two minor objections, I think the above is sufficient to show that Mr. Beresford's conclusion on paragraph 8 is not only open to very grave objections, but that it entirely fails to explain that enormous lifting power observed.[6] The rate of pressure is undoubtedly much greater than the pressure due to the height.

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

not to the maximum intensity of pressure at any moment, which depends much more on the *modulus of elasticity* than on the *co-efficient of elasticity*, which is evidently what Mr. Eliot alludes to. Thus take the case of equal weights of soft iron and India rubber striking a perfectly hard surface with the same velocity. The *total* mechanical action during impact would, as Mr. Eliot truly says, be greater in the case of the India rubber, but the pressure between the surface and the impinging body would at any moment be less in the case of the India rubber in the inverse ratio of the relative yield or compression of the rubber and iron during impact.

J. S. B.

[4] Rather upon the velocity with which the water meets the floor?

J. S. B.

[5] Yes, because the greater the contraction, the greater must necessarily be the velocity, but the velocity can never exceed that due to the fall.

J. S. B.

[6] The lifting power observed is really never so great per square foot as my rule gives.

J. S. B.

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 even greater than this.[7]

The eroding action of water moving with so great a velocity, is necessarily very great.[8]

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.

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.

There seems to me to be two[9] methods of attempting to diminish the action or the fall: *1st*, to have a large hollow at the base so that there may be a considerable cushion of

[7] Can never be greater relatively to the floor.
J. S. B.

[8] This is quite another matter, with which I deal in paragraph 15 of my Note on the Keroni Weir.
J. S. B.

[9] Both of these methods have been tried in practice, with success; but making a deep cistern where the spring line is near the surface is often prohibitively expensive. Besides, the

water to receive the falling mass. The water falling on this will distribute the pressure over the whole of the hollow of basin, instead of allowing it to fall upon only a portion of the bed, which would give rise to very unequal pressure on this bed masonry, and which I imagine is much more dangerous than considerable pressure equally distributed over the whole.

2nd. To break up the falling mass of water partially into spray. The resistance 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 pressure consequently less.

object of my Note was to try and investigate the maximum effect of falling water when no cistern is provided. Present fall construction is based on no scientific principle, and so no two Engineers design alike.

J. S. B.

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. 461W 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 information.

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
1 Copy MS. Addendum to " } Note from Mr. Beres-
1 Copy Mr. Eliot's Note on " } ford.
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.

B. para. 2. *Minimum Water on Floor.*—This appears to be 8 feet, so that the floor can apparently never be exposed to the direct action of the full fall of water.

B. para. 3. *Effect of a Fall.*—The *first* effect is an Impact; after which the permanent effect must be admitted to be Simple 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].

B. para. 4. *Effect of Jet.*—The permanent effect of a Jet is stated in Rankine's Applied Mechanics, Art. 648, to be a pressure 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 ‖ *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 $\perp^r$ 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 × Jet-section,	90°,	2 × height due to velocity. [This is the maximum effect].
	< 6 × Jet-section,	< 90°,	< the above.
	= Jet-section,	Acute,	Height due to velocity.

Mean and maximum pressure-intensity.—The mean pressure-intensity is of course the Total Pressure ÷ 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 × mean pressure-intensity.
Wide jet, ...	Wedge,	2 × 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,	⊥r to Plane,	> 6 × Jet-section,	$\frac{1}{2}$ × height due to velocity,	Height due to velocity.
		= Jet-section,	Height due to velocity,	3 × height due to velocity.
Wide and Flat,	⊥r to Plane,	> 6 × Jet-section,	$\frac{1}{2}$ height due to velocity ?	$\frac{3}{2}$ × height due to velocity ?
		= Jet-section,	Height due to velocity ?	2 × 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 in-"directly 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 por- "tion 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. *

B. para. 8. 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.

B. para. 7. 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.

B. para. 8. 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.

B. para. 9.

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.

B. para. 10.

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 inpinged.

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 complexity, 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; $g = 32{\cdot}2$, 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 $\frac{1}{20}$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 23 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. 23, 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 Indian 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.

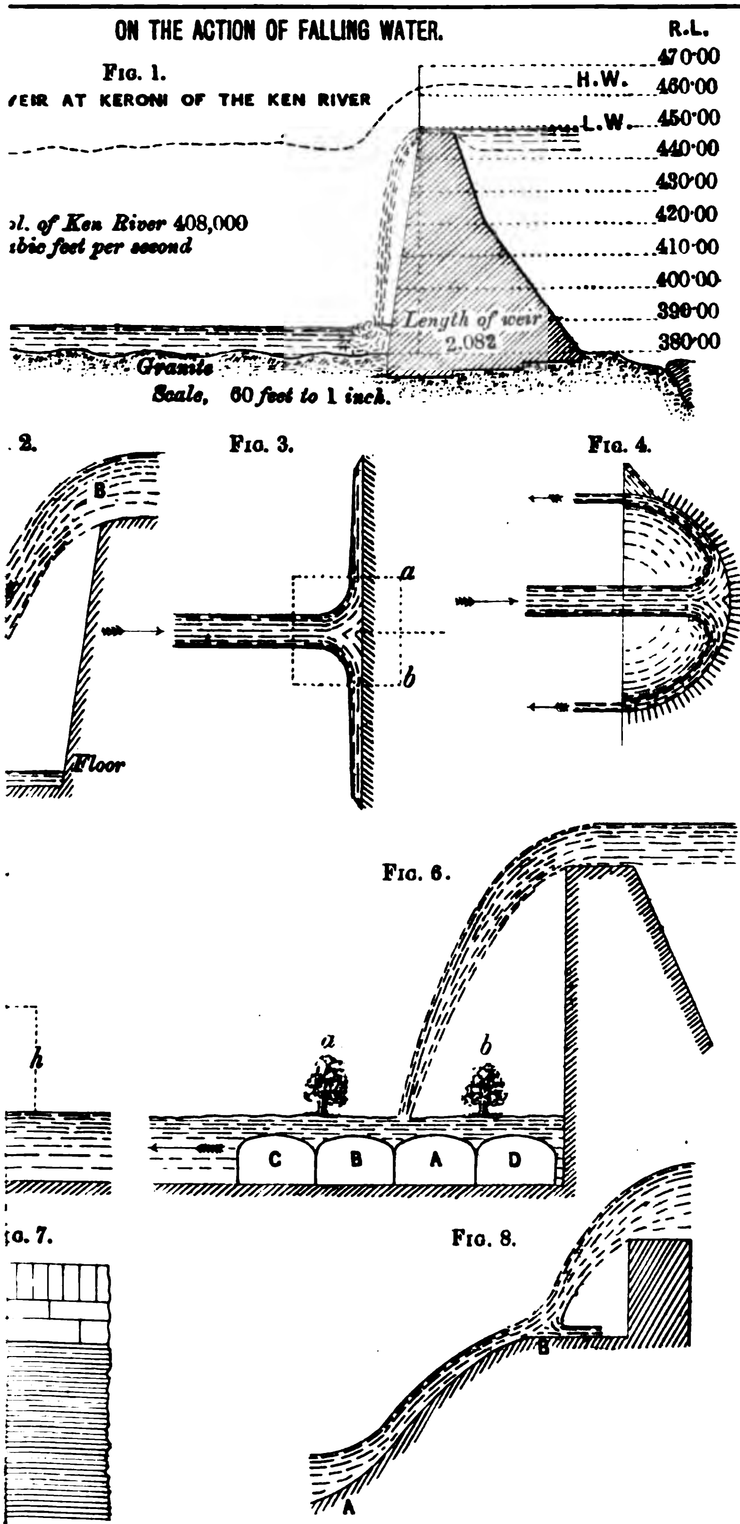
Experiment No. 5 (*see Plate* X.) was made in imitation of an ordinary canal fall, where AB is the face of the crests or drop wall, BC the floor, and AB, BC, side walls. The head or drop producing velocity was 40 inches throughout, and the adjustable plate AB was moved about in order to ascertain the position giving a maximum head in the pressure tube. The maximum intensity of pressure on the plate was found to be $\frac{35}{40}$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 $\frac{3}{4}$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.

PLATE I.



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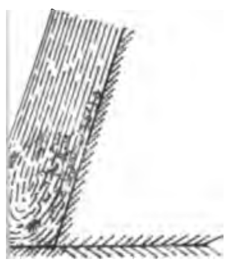
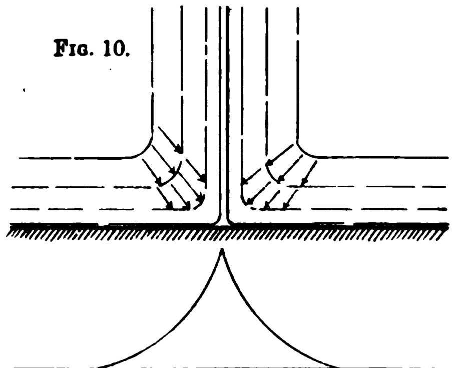


Fig. 10.



Curve of pressure

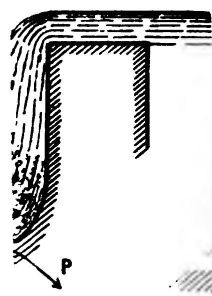
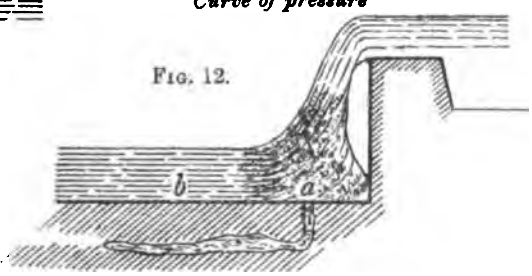


Fig. 12.



. 13.

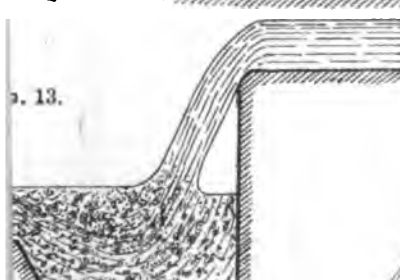
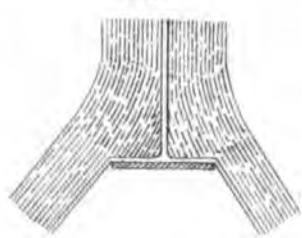


Fig. 14.



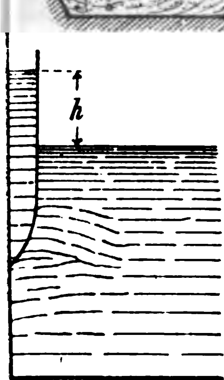
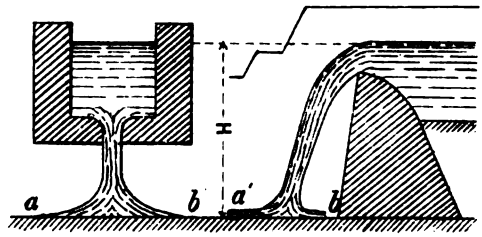


Fig. 16.



Thos D. Bona, Supdt.

PLATE III.

ON THE ACTION OF FALLING WATER.

7.

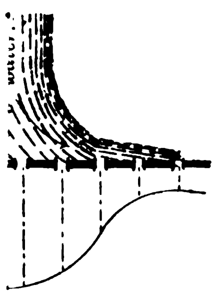


Fig. 18.

ENLARGED SECTION THROUGH FUNNEL AND PIPE

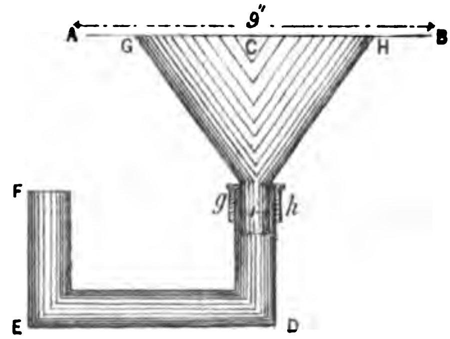


Fig. 19

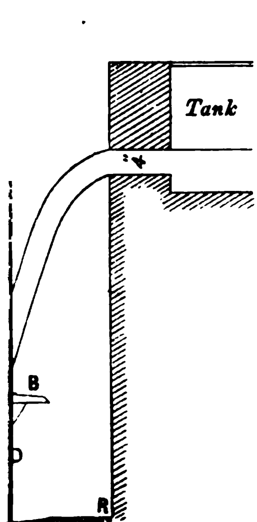


Fig. 20.

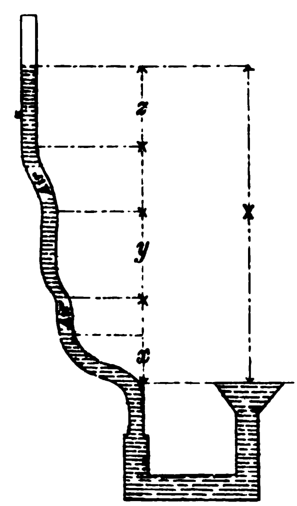


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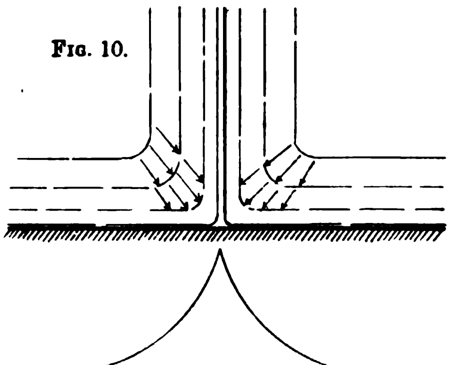
Fig. 10.



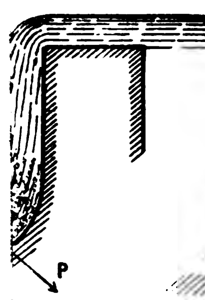
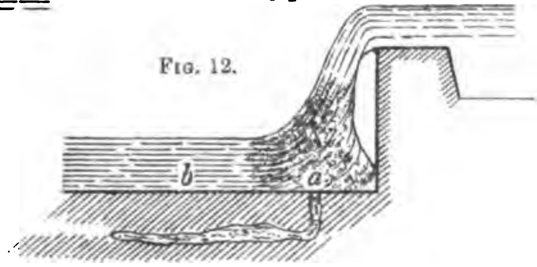


Fig. 12.



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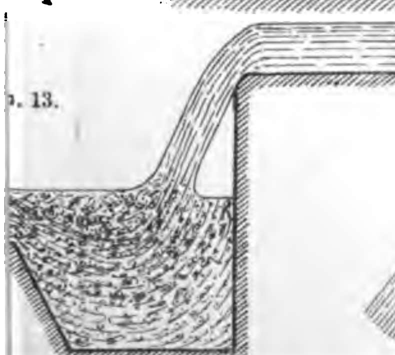


Fig. 14.

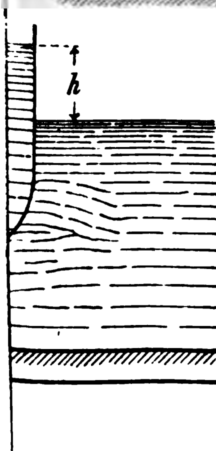
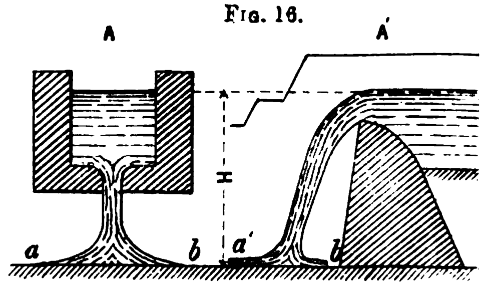


Fig. 16.



ON THE ACTION OF FALLING WATER.

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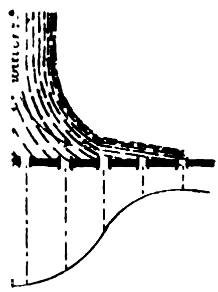


FIG. 18.

ENLARGED SECTION THROUGH FUNNEL AN

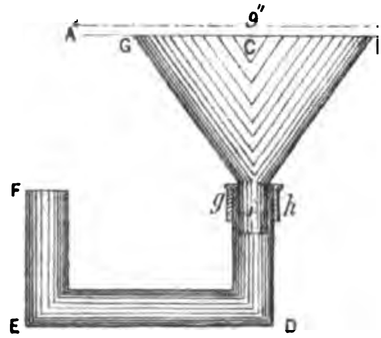


FIG. 19

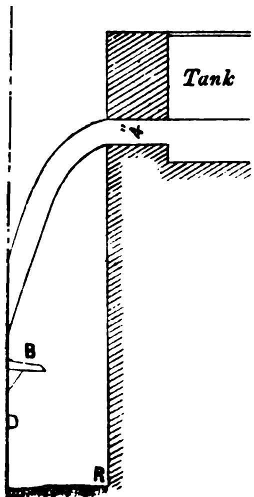
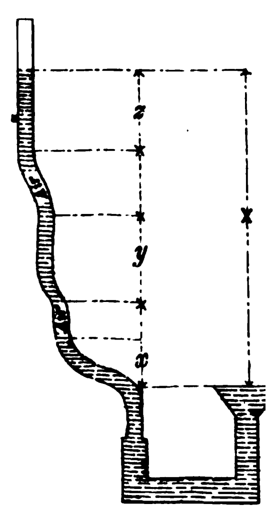


FIG. 20.



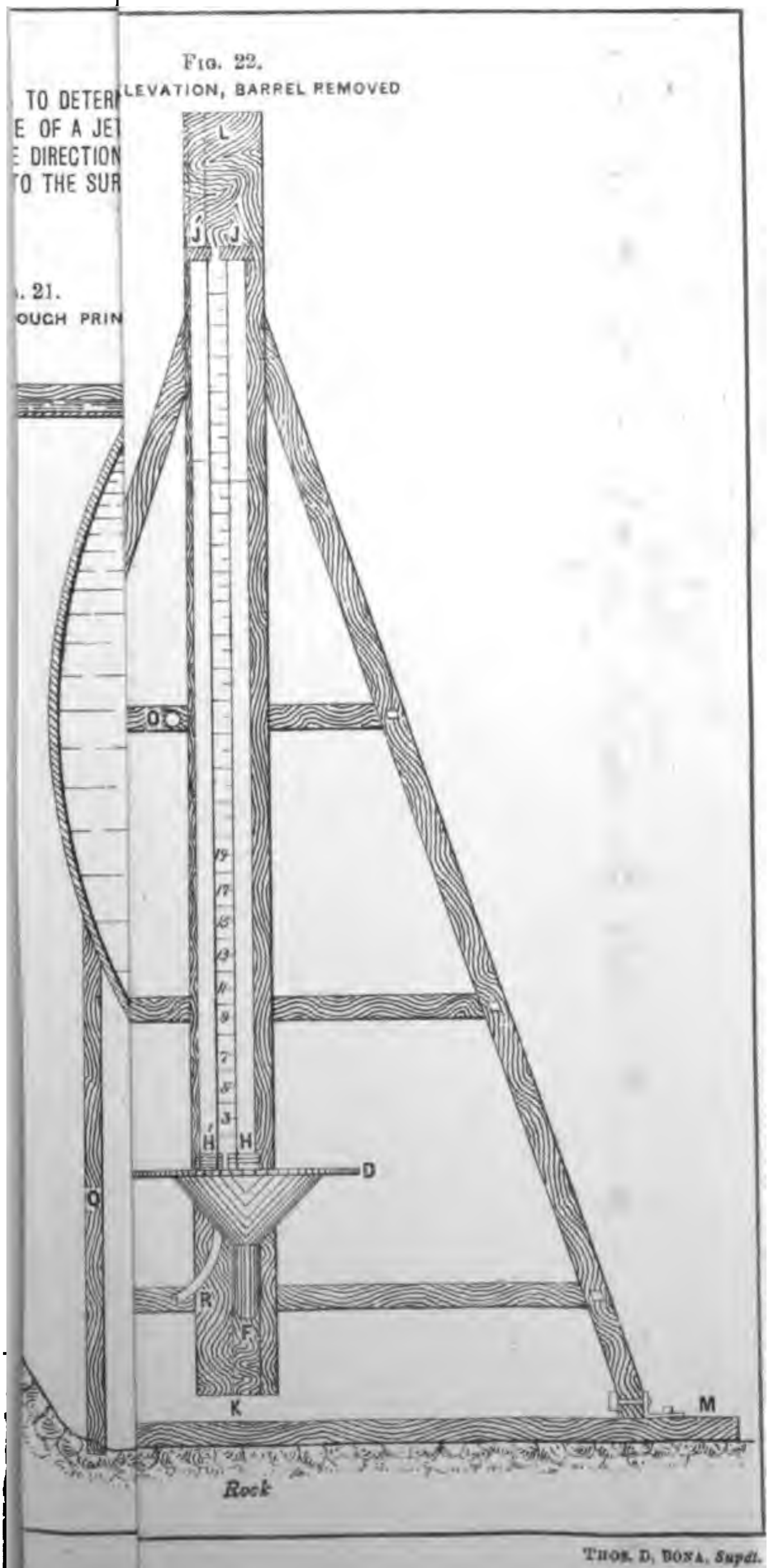


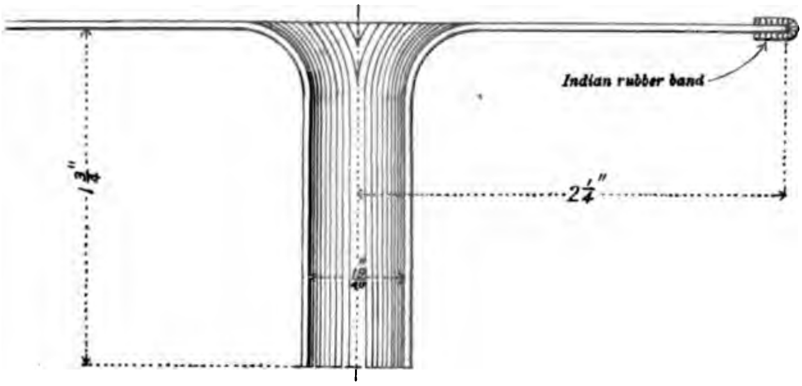
Fig. 22.
LEVATION, BARREL REMOVED

Thos. D. Bona, Supdt.

ON THE ACTION OF FALLING WATER.

Fig. 23.

FULL SIZE SECTION OF TURNED BRASS MOUTH PIECE



Experiment No. 1—*Figs.* 23 & 24.

[E]xperiment on the distribution of the pressure caused by a cylindrical jet of water nearly ½ inch in diameter falling perpendicularly on a horizontal brass plate 9 inches in diameter.

[Po]sition of hole relatively to axis of jet.	Head producing velocity.	Head in pressure tube.	Remarks.
	Inches.	Inches.	
4	48	0	
5	"	½	
6	"	1	
7	"	8½	
8	"	8	
9	"	14	
10	"	21	
11	"	27	
12	"	..	Not observed.
13	"	87	
14	"	..	Not observed.
15	"	89·5	
16	"	40	
17	"	40½	Probably axis of jet.
18	"	89	
19	"	87½	
20	"	85	
21	"	83½	
22	"	81	
23	"	21	
24	"	..	
25	"	..	Not observed. (25–31)
26	"	..	
27	"	..	
28	"	..	
29	"	..	
30	"	..	
31	"	..	
		..	

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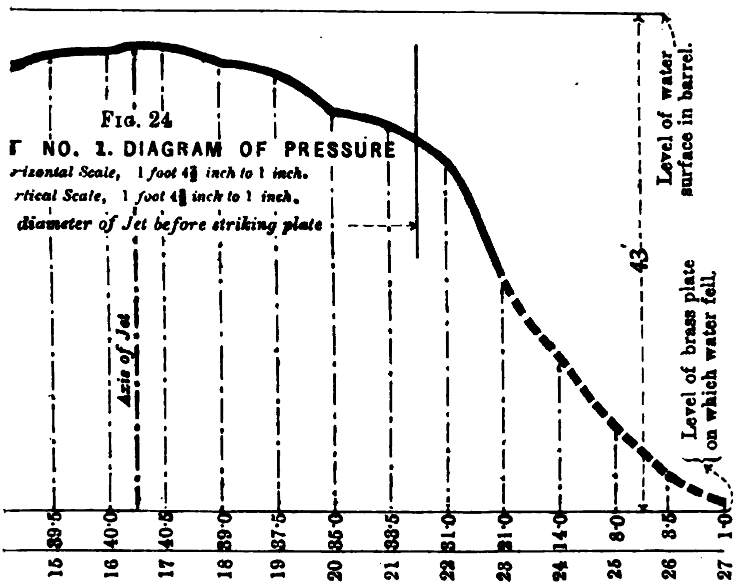

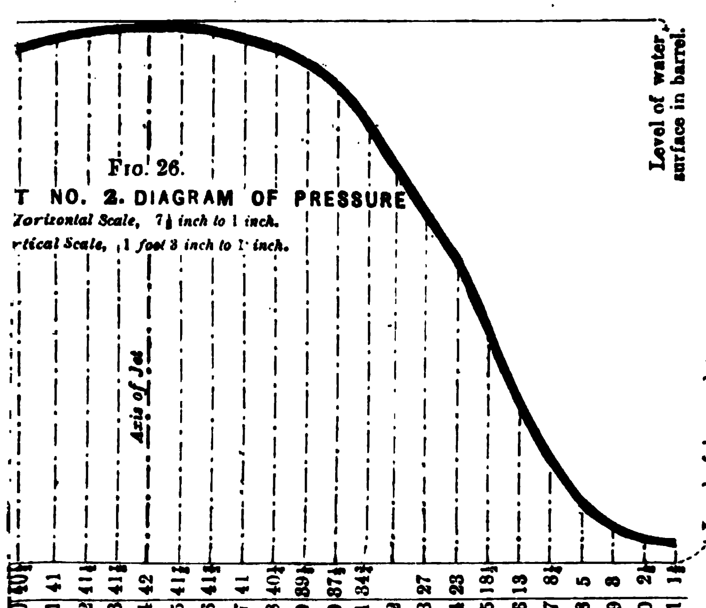

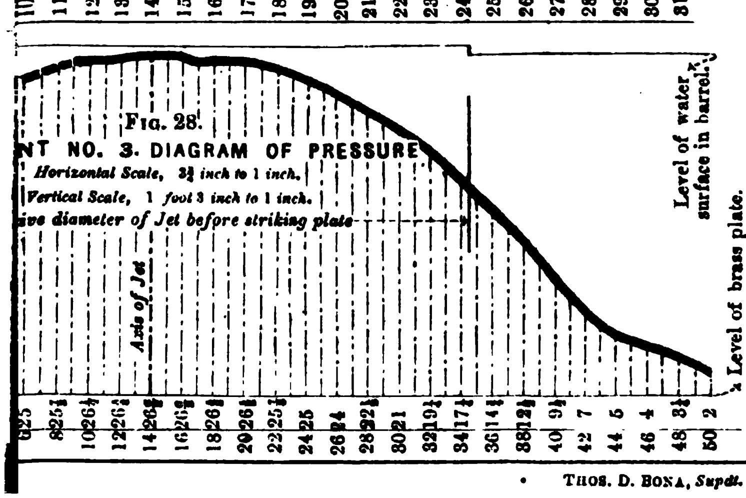

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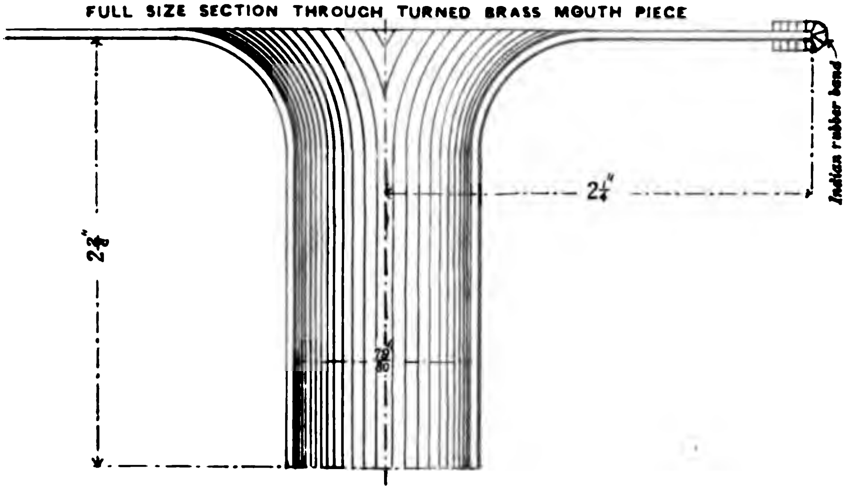
Fig. 25.

FULL SIZE SECTION THROUGH TURNED BRASS MOUTH PIECE



Experiment No. 2—*Figs.* 25 & 26.

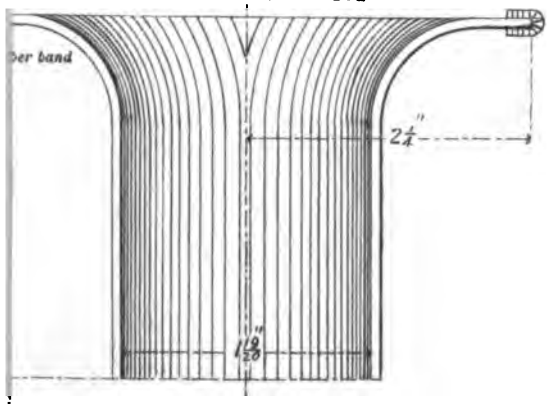
Experiment on the distribution of pressure caused by a cylindrical jet of water nearly 1 *inch in diameter falling perpendicularly on a horizontal brass plate* 9 *inches in diameter.*

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	,,	41⅞	
14	,,	42	Probably axis of jet.
15	,,	41⅞	
16	,,	41⅝	
17	,,	41	
18	,,	40¼	
19	,,	39½	
20	,,	37½	
21	,,	34¾	
21½	,,	33½	
22	,,	..	Not observed.
22½	,,	29	
23	,,	27	
24	42¼	23	Probably opposite outer surface of jet.
25	,,	18½	
26	,,	13	
27	,,	8¼	
28	,,	5	
28½	,,	3¾	
29	,,	3	
29½	,,	2½	
30	,,	2¼	Note on Fig. 27 applies to this experiment.
30½	,,	1¾	
31	42½	1½	
31½	,,	1½	
32½	,,	1¼	
33½	42¼	1	

ON THE ACTION OF FALLING WATER.

Fig. 27.

TWO-THIRDS SIZED SECTION
OF BRASS MOUTH PIECE



Experiment No. 3—*Figs.* 27 & 28.

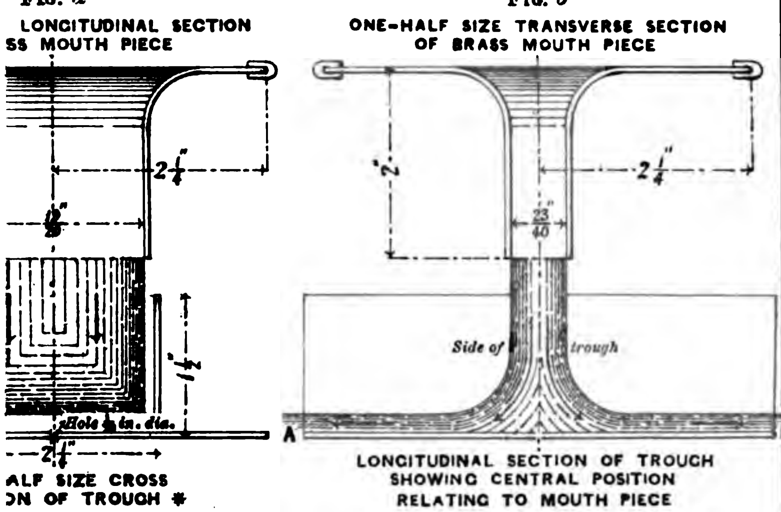
on the distribution of pressure caused by a cylindrical jet inches in diameter falling perpendicularly on a horizontal plate of brass 9 *inches in diameter.*

Head in pressure tube.	Remarks.	Position of hole relatively to axis of jet.	Head producing velocity.	Head in pressure tube.	Remarks.
nches.			Inches.	Inches.	
2		20	27⅛	26⅝	
2½		19	27⅛	26⅝	
...	Not observed.	18	27⅛	26⅝	
3¼		17	27⅛	26¾	
3½		16	27⅛	26⅞	
4		15	27⅛	26⅞	Probably axis of jet.
4½		14½	...	...	
5		14	27⅛	26⅞	
6¼		13	27⅛	26⅞	
7		12	27⅛	26¾	
8		11	27⅛	26½	
10	Max.	10	27⅛	26⅜	
9	Min.	9	27⅛	26¼	
11	Max.				
10½	Min.				
12½					
13½					
...	Not observed.				
...					
	Probably opposite surface of jet.				
...					
17					
18					
19¼					
20¼					
21					
21⅜					
22½					
23¼					
24					
24½					
25					
25½					
25⅞					
26⅛					

Note.—The numbers indicating position in column 1 have reference to a scale graduated to twentieths of an inch. The observations were noted at every $\frac{1}{20}$th of an inch horizontally on a vertical plane passing through the axis of jet.

ON THE ACTION OF FALLING WATER.

Fig. 29.



EXPERIMENT No. 4—*Figs.* 29 & 30.

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

hole o axis	Head producing velocity.	Head in pressure tube.	Remarks.
	Inches.	Inches.	
	40¾	2	
	"	..	Not observed.
	41	3	
	"	3¾	
	"	5	
	42½	11	
	"	13½	* *Note.*—The trough was moved from B towards A, and the pressure on hole noted at every twentieth of an inch moved.
	"	15½	
	"	17	
	"	21	
	"	22	
	"	27	
	"	30	
	"	31	
	"	33	
	"	32	
	"	33	
	"	34	Mean—35 was max.
	"	35	" —35½ "
		35½	Steady; probably axis of jet.
		35½	Max.
		34½	Max.
		31	Mean.
		31½	Mean.
		26	Fluctuating.
		24	
		22	

ee. THOS. D. BONA, *Supdt.*

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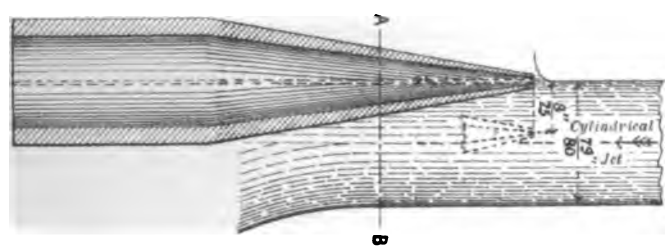
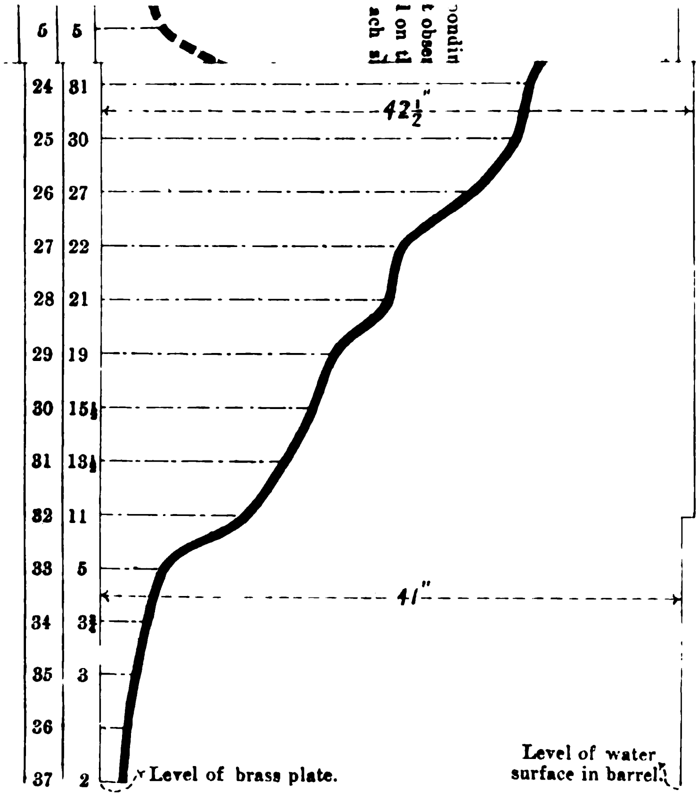




Experiment No. 8—*Fig.* 33.

Position of nozzle as indicated by scale.	Head in barrel.	Head in pressure tube.	Remarks.
*14	$37\frac{9}{16}$	34	* The above diagram shows in section the position of nozzle corresponding to No. 14 on scale.
$14\frac{1}{2}$	"	$37\frac{3}{8}$	
15	"	$37\frac{1}{3}$	
16	"	$37\frac{1}{2}$	*Note.*—The nozzle was moved from A towards B by $\frac{1}{16}$ of an inch at a time, the axis of nozzle traversing a plane through axis of jet.
17	"	$37\frac{1}{8}$	
18	"	$37\frac{1}{2}$	
19	"	$37\frac{1}{8}$	
20	"	$37\frac{1}{3}$	
21	"	$37\frac{1}{8}$	
†22	"	$37\frac{1}{2}$	† The dotted line shows nozzle in the position corresponding to No. 22 on scale.

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 Debra 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′ × 10″ × 5″, containing 3·47 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 sleepeers 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 perfect 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 pie per sleeper. The rate in Germany was stated to be 1*d*. 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 Reclues 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, *viâ* 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 Lieut. 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 Reclues 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 Matacbin 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.*:—

1*st.* 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.

2*nd.* 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 41⅓ 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 4½ 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 embankments, 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 123¾ 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
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 10½ miles long, and involving seven tunnels with an aggregate length of 13,700 feet, and two siphons of 4,530 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 41½ 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 chancès 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
Total length of canal, ..	61·74
Lake navigation, ...	56·50
Slack water navigation by the river San Juan, ...	63·02
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
Total for Western Division, ..	21,680,777

Middle Division, or lake navigation, 56·50 miles.

Dreding 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, ...	13,389,398
Dams Nos. 1, 2, 3 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 then $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, ...	32,433,797
„ rock, „	14,435,477
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, ...	31,535,500	32,433,797	..	898,297
„ rock, ...	10,393,537	14,435,477	..	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	15,888,235	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 10·37 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.
63 miles of river navigation, at 6 miles an hour, ...	10½	„
56⅔ miles of lake navigation, at 10 miles an hour,.. ..	5⅔	„
21 locks, at 20 minutes each, ...	7	„
Total, ..	38⅔	„

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 $\frac{29}{30}$ of the volume of the San Juan, leaving but $\frac{1}{30}$ 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.

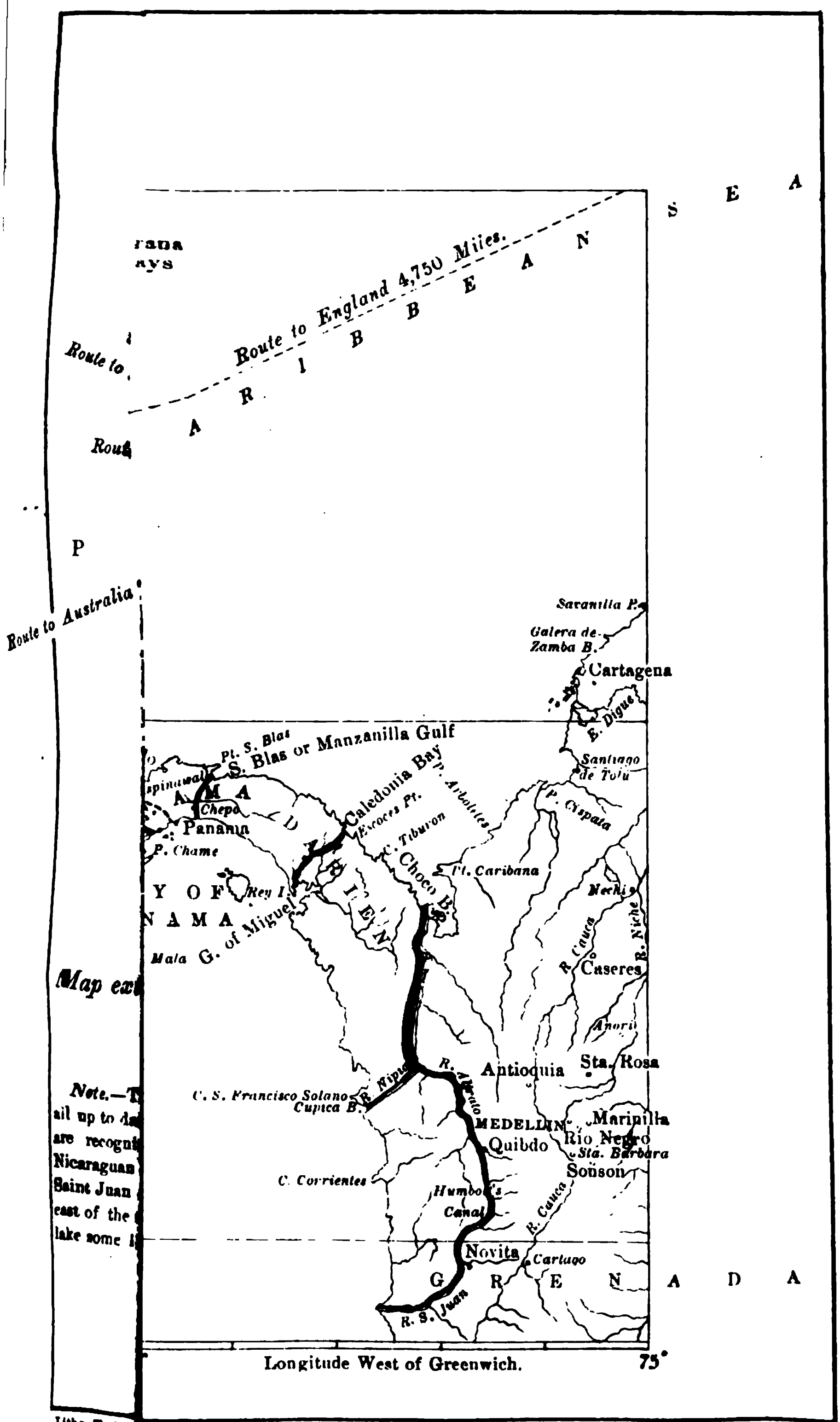
2nd. That a canal with locks can be so constructed as to satisfy all the requirements of ocean navigation, at a cost within the possibility of a private undertaking, with reasonable expectations of liberal returns and without overtaxing the commerce of the world intended to be benefited thereby.

3rd. That while a canal with locks seems to be practicable, *viâ 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.



Litho. T. C.

THOS. D. BONA, Supdt.

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 Poutrelles, 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. LA., 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-au-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. *Plate* II., *Fig.* 4.—The system of M. Fourneyron is very similar to the American system, except that the shutters or gates are hinged vertically 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 1½ inches below the centre of gravity of the shutter, and about 1⅞ 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 trolly 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 cill, 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 raipidly 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 8¼ 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 1¾ 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 8½ 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 1¾ inches. The navigable pass is 93 feet 4½ inches long, the regulating weir 82 feet.

The shutters of the regulating weir are of wood, they are 11 feet 6¼ inches long by 6 feet 5½ 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 3¾ inches external diameter 1½ 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 11¼ 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	8	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	3	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	8	18	8
XI. Boulé, ...	18	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.
Nouvelle Passe Navigable, ... } M. Boulé.
Dans le Barrage de Port à l'Anglais, ... }
Manuel de l'Ingenieur, ... } 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 Vanne-Déversoir, is near the Pont-Neuf in the centre of Paris.

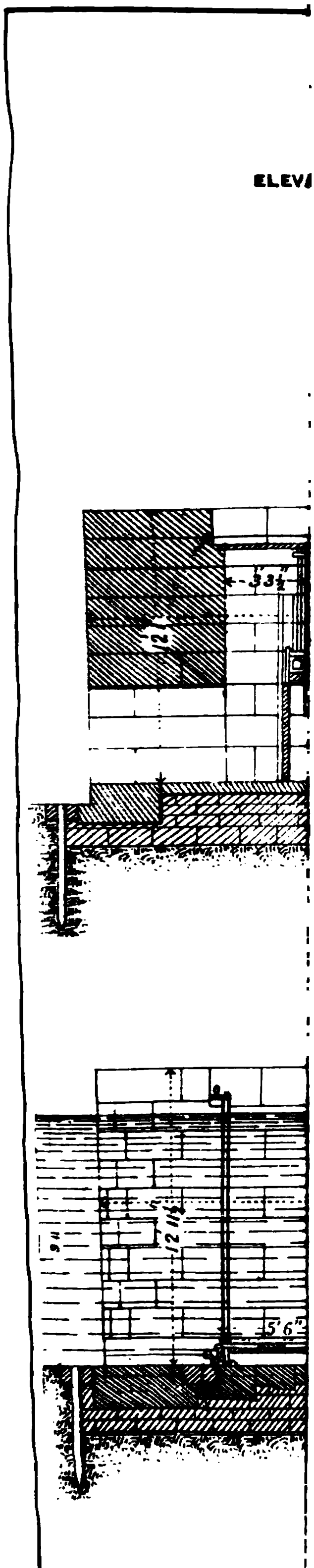
Steamers run up the Seine from Paris to Charenton; the weir of the Port à l'Anglais, the largest weir of M. Chanoine's system, is within a mile or so of the place where the steamers stop.

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.

II.



II.

d 7.)

Fig. 6.

F PLAN OF THE VANNE

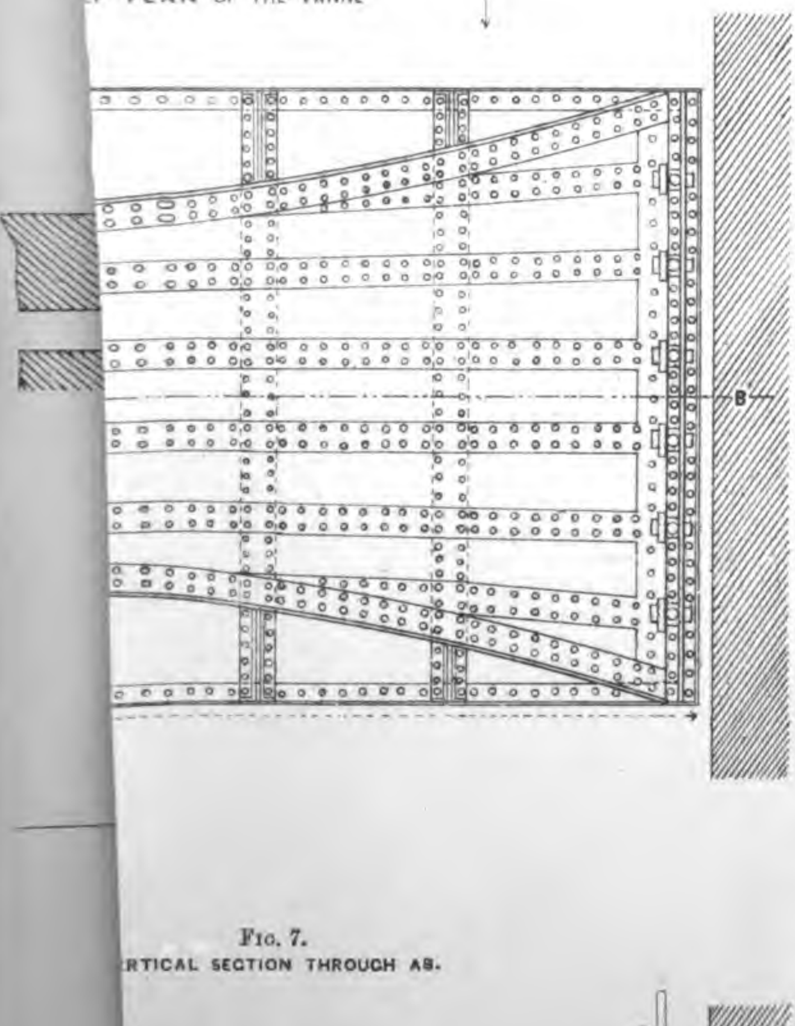


Fig. 7.

RTICAL SECTION THROUGH AB.

THOS. D. BONA, Supdt.

DAMS.

3, 4, 6, 7, 8, 10, 11 *and*

6 7 8 9 10

igures 5 and 9.

1

ures 13 and 14.

1

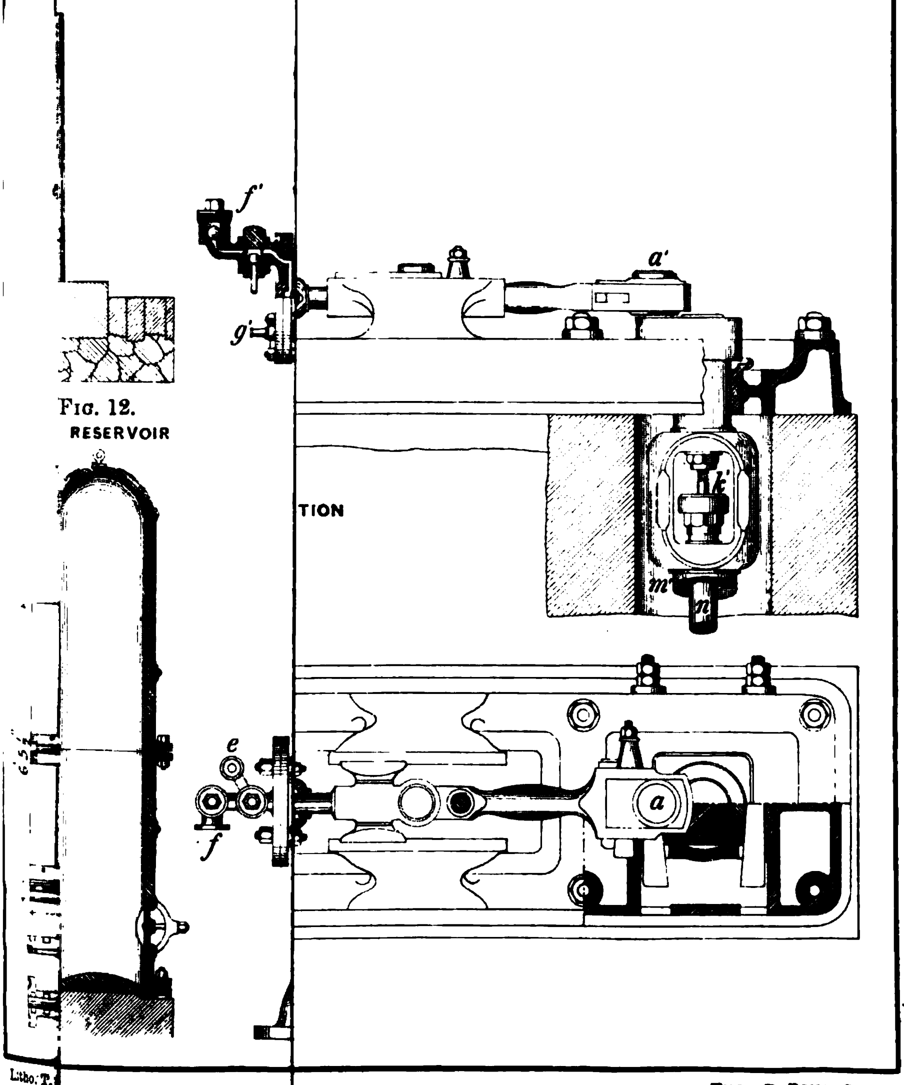


Fig. 12.

RESERVOIR

Litho: T.

THOS. D. BONA, *Supdt.*

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 39⅜ 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 Wadhwán 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 Wadhwán 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 Wadhwán 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 2½ 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 5·83 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 comparatively 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 49·03, 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	1,58,28,683	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.	Rs.	Rs.	Rs.	Rs.	Rs.
General Superintendence, ...	158·56	1·04	154·86	0·190	224·86	0·53
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	0·10	2·40	0·003	...	...
Unclassified expenditure, ...	13·05	0·08	17·56	0·022	18·00	0·05
			1146·81	1·404	1125·71	2·57
Less, ...	...	...	429·70	0·527	14·33	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

	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, ...	3·38	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	1·38	0·43	1·03
Total, ...	2·80	7·82	4·65	14·21	3·03	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	12·79
Carriage and waggon expenses, ...	2·80	4·64	3·03
Traffic expenses, ...	4·61	4·31	7·87
General charges, ...	5·77	1·99	6·71
Total, ...	35·76	26·55	42·96

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	
RAJPUTANA STATE RAILWAY.	Tons.	Tons.	Tons.	Tons.
Passenger trains, ...	12·33	87·73	100·06	123
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	170
Goods trains, ...	89·53	130·15	219·68	
Mixed trains, ...	60·16	127·67	187·83	

	Freight	Train	Total	
Bombay, Baroda and Central India Railway.	Tons.	Tons.	Tons.	Tons.
Passenger trains, ...	12·28	108·46	120·74	286
Goods trains, ...	183·50	276·36	459 86	
Mixed trains, ...	83·12	194·81	277·93	

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 × 40·29 = 4,483
Bombay, Baroda and Central India, ... 316·5 × 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	13·7	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
	Pies.	Pies.	Pies.
Average of all descriptions of passenger traffic, ...	29·5	17·41	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	1,01,75,360	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 Wadhwán 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,	$\frac{3}{4}$th double line.
Bombay, Baroda and Central India has been ...	„ 16,975,	do.	$\frac{1}{20}$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, ...	35·77 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, ...	111·3 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. 2,13,943,

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. 33,608, although they carried 1,789 tons *more* than in 1876. This traffic which forms over 46¼ 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	1,236,741	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 stoodat 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		Per cent
1875, ...	2·71	instead of	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 Wadhwán 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	1·38	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
Rails.				
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
Sleepers.							
Wooden,	Number,	24,665	17,308	88,572	40,328	9,078	9,231
	L. yards,	22,646	22,646	...	...	956	498
Iron, ...	Pairs,	30	7,387	12,171½	60,415½	...	...

15. Had the maintenance of the Rajputana line been done at the same

* (Should be Rs. 1,434 and 0·86).

† Exclusive of Special Expenditure amounting to Rs. 1,86,476 the rate per mile maintained was Rs. 1,789·34 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, ...	1,037
Bombay, Baroda and Central India, ...	194
Rajputana, ...	73

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. 2,603 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,	70,497	7,270
Rajputana, ...	30,015	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,	43·24	„ „
Rajputana, ...	35·77	„ „

But applying the ton mile test the result would be—

Great Indian Peninsula, ...	1·4341	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, ...	1·3392	pies per ton per mile.	
*Bombay, Baroda and Central India,	1·3183	„ „	(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.

	Pies.
Rajputana, ...	7·79
Great Indian Peninsula, ...	4·59
Bombay, Baroda and Central India, ...	4·12

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, ...		1282·18	444·07	396·30	
2. " of line maintained, ...		1278·76	430·78	396·30	
3. " of track "		1815·61	527·57	445·15	(Including
4. Ton miles, ...		2,119,222,775	376,721,980	120,876,767	sidings).
5. Train miles, ...		8,480,578	1,207,599	828,012	
6. Number of stations, ...		*158	74	45	* Including
7. Average distance apart, ...		8 miles.	6 miles.	9 miles.	State Railways.
1. Capital expended, ...	£	22,145,353	7,538,220	2,538,240	
2. Percentage of profits, ...	°/o	6·98	5·50	3·12	
3. Gross earnings, ...	Rs.	3,27,74,150	77,98,912	26,96,687	
4. " expenditure, ...	"	1,58,28,683	32,73,330	18,33,367	
5. Net Profit, ...	"	1,69,45,467	45,25,582	8,63,320	
6. Percentage of expenses to earnings, ...	°/o	49·08	42·84	68·00	
7. Gross earnings per ton mile, ...	Pies.	2·97	3·97	4·28	
8. " expenditure, ...	"	1·43	1·67	2·91	
9. Profit, ...	"	1·54	2·30	1·37	
10. Cost of Maintenance, ...	Rs.	18,33,939	†7,70,812	4,65,953	† Excluding
11. " " per mile of track maintained,	"	1,010·10	1,461·06	1,046·73	Rs. 1,86,476
12. " " " line "	"	1,434·15	1,789·34	1,175·76	for special
13. " " per 1,000 ton miles, ..	"	·86	2·04	3·85	charges.
14. Locomotive Expenses, ...	"	63,56,572	9,65,492	7,03,378	
15. " " per 1,000 ton miles, ..	"	3·01	2·58	5·83	

Summary of the principal items referred to in the foregoing observations on Lieutenant Pilkington's Memo.—(Contd.)

No.	Item	Unit	For the year 1877. Great Indian Peninsula	Bombay, Baroda and Central India	Rajputana	Remarks
16.	CARRIAGE AND WAGON EXPENSES, ...	Rs.	24,43,115	2,28,353	1,45,098	
17.	" " per 1,000 ton miles,	"	1·15	·61	1·20	
18.	" " " 1,000 vehicle "	"	14·16	7·29	7·82	
19.	Average number of vehicles constantly under repair, ..	No.	1,087	194	78	
20.	TRAFFIC EXPENSES (Total), ...	Rs.	22,56,926	5,90,869	2,39,018	
21.	" " per 1,000 ton miles, ...	"	1·06	1·57	1·97	
22.	Average cost of working each station, ...	"	6,051	4,309	2,603	
23.	Total number of passengers carried, ...	No.	47,12,145	52,16,821	13,50,688	
24.	" tons of goods carried, ...	Tons.	1,514,727	588,009	204,809	
25.	Average number of passengers booked at each station,	No.	29,823	70,497	30,015	
26.	" tonnage of goods " " ..	Tons.	9,587	7,270	4,551	
27.	" receipt per ton per mile for goods traffic, ..	Pies.	8·81	10·70	13·79	
28.	" cost " " " ..	"	4·59	4·12	7·79	
29.	" profit " " " ..	"	4·22	6·58	6·00	
30.	" capacity of goods vehicles,..	Tons.	6·50	8·10	5·00	
31.	" load " "	"	3·89	3·74	2·81	
32.	" freight of goods train, ...	"	89·53	183·50	55·29	
33.	" " passengers "	"	12·47	12·28	12·33	
34.	" " mixed "	"	60·16	83·12	27·42	
35.	" number of vehicles per train — goods, ..	No.	24·75	50·00	24·00	
	— passengers, ..	"	16·	14·	22·	
	— mixed, ..	"	13·7	18·	8·	

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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 6·39*s.* per train mile, against 4·84*s.* in 1877; of the Great Indian Peninsula 5·58*s.*, against 3·39*s.* in 1877. The East Indian, I may add, was 3·62*s.* in 1871, against 2·59*s.* 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 30 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 183·50 tons.

This must be an error. No Indian Railway has yet reached this average load. The true load was, I believe, 123·5 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 1*s*. 10*d*., 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,	£ 23,084,484	£ 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. 3 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 11¾	s. d. 8 5	s. d. 3 9¼ (Note the average fares charged).

REVENUE—(*continued.*)

Passenger Traffic	Great Indian Peninsula, in 1874	Bombay, Baroda, and Central India, in 1874	Rajputana, in 1873
(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 20,071,392	No 4,234,639	No 7,610,336
(17). Average number of passenger vehicles in a passenger train,	No 18·7	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 2¼
(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), ...	$\frac{12}{100}$	$\frac{25}{100}$	$\frac{16·5}{100}$

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, ..	£ 1,369,033	£ 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 36,500,973
(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 15,363,683	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, *see* 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 5¾ 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. ·762	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, ...	$\frac{38}{100}$	$\frac{34}{100}$	$\frac{48}{100}$

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 3*s.* 9*d.*; on the Bombay and Baroda 4*s.* 9*d.*; on the Rajputana 3*s.* 2¾*d.* The working expenses per passenger mile are the same on the

Bombay and Baroda and the Rajputana, *viz.*, ·197*d.*, but greater on the Great Indian Peninsula than on either, namely, ·203*d.* The working expenses per ton mile are greatest on the Rajputana, ·63*d.* against ·51*d.* on the Great Indian Peninsula, and ·45*d.* 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
	Miles	Miles	Miles	Miles	Miles
Length of line open, ...	1,504	858	544	611	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	830	520
Cost of carrying a passenger one mile, ...	*d.* ·15	*d.* ·234	*d.* ·1059	*d.* ·1327	*d.* ·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	229 5	400	120	240
Cost of carrying one ton one mile,	*d.* ·26	*d.* ·895	*d.* ·366	*d.* ·77	*d.* ·63
Cost of running a train (passenger or goods) one mile, ...	*s. d.* 2 10¼	*s. d.* 4 0¼	*s. d.* 2 9½	*s. d.* 3 2½	*s. d.* 3 2¾

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 versâ.* 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 indeed 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,	31·64
Fixed carbon,	43·42
Ash,	13·94
	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
	100·0

and dried coal would yield 64·4 per cent. of the same.

The ash consisted of—

Silica, ...	57·93	
Titanic acid, ...	0·80	
Alumina, ...	22·74	
Peroxide of iron, ...	8·71	= Metallic iron, 6·10 per cent.
Lime, ...	6·04	
Magnesia, ...	1·29	
Potash, ...	0·94	
Phosphoric acid, ...	0·06	
Sulphuric acid, ...	0·51	
	99·02	

The above analysis of Warora coal corresponds with those given of this and of other coals of the district in the Memoir by Mr. T. W. H. Hughes on the Wardha Valley Coalfield, pages 99 to 103, (Memoirs of the Geological Survey of India, Vol. XIII., Part 1).

The sulphur contained in the coal is present chiefly in the form of pyrites, which occurs in part in large pieces that may be picked out, in part in nests, and in part spangles the surface of occasional blocks of coal.

In an experiment made to test the extent to which it would be possible to remove the sulphur, by washing, a sample of coal, in coarse powder, which contained by analysis 1·137 per cent. of sulphur, was washed, with the result that the washed coal contained 0·86 per cent. of sulphur, and the residue 5·23 per cent. By powdering the coal more finely, and by classifying and washing it with care, a larger proportion of the sulphur that it contains may no doubt be removed, but it is very questionable whether the whole or nearly the whole can be got out by any practicable process.

The relatively small amount of fixed carbon that is contained in these coals, and the large percentage of water that they retain, even after they have been stored under cover for months, indicate that they are more closely allied to lignites than to ordinary coals; and this view is confirmed by their behaviour when coked, and by the ultimate analysis given of one of the varieties of Sásti coal, on pages 102 and 103 of Mr. Hughes's Memoir.

Lignite dried in the air retains generally 15 to 20 per cent. of water, or more, which may be driven off by exposure to a temperature of 212°

Fahr. Warora coal that had been stored under cover, in London, for more than a year retained, by Mr. Riley's analysis, 11 per cent.

Dr. Percy gives the following as the relative composition of wood and peat, of dry lignite, and of coal; the proportion of carbon being taken in each case as equal to 100 (Metallurgy, French edition, 1864, Vol. I., page 127).

	Carbon	Hydrogen	Oxygen	Hydrogen in excess
Wood (mean of 26 analyses), ..	100	12·18	83·07	1·80
Peat, ...	100	9·85	55·67	2·89
Lignite (average of 15 varieties), ..	100	8·37	42·42	3·07
10-yard coal (South Staffordshire),	100	6·12	21·23	3·47
Tyne steam coal, ...	100	5·91	18·32	3·62
South Wales coal (Pentrefelin colliery), ...	100	4·75	5·28	4·09

The "hydrogen in excess" is that available as a source of heat; that is, the quantity in excess of the amount required to form water with the oxygen present.

The composition of the Sásti coal is as follows:—

	Carbon	Hydrogen	Oxygen and Nitrogen
A. Shaft, good coal (average), ...	63·61	3·40	20·98
B. „ (best samples), ...	74·07	4·90	9·92
C. „	74·33	4·60	12·15

Taking the proportion of carbon as equal to 100, as in the table above, this is equivalent to—

	Carbon	Hydrogen	Oxygen and Nitrogen	Hydrogen in excess
A. Shaft, ...	100	5·35	32·98	1·23
B. „	100	6·61	13·39	4·94
C. „	100	6·19	16·35	4·15

In estimating the proportion of hydrogen in excess, the nitrogen contained in the coal is calculated as oxygen, but as the amount of this, in coals and lignites, rarely exceeds 2 per cent., the error is unimportant.

Comparing the compositions of the three varieties of Sásti coal with those of different fuels, as given above, it will be seen that while the coals from the B and C shafts contain an exceptionally large amount of hydrogen, in excess of that required to form water with the oxygen present, and are thus fuels of considerable heating power, and resemble in composition the true coals of Europe; that obtained from the A shaft, which, from its lower percentage of carbon, is probably more similar in character to Warora coal, contains even less available hydrogen than is commonly found in wood.

The solidity and hardness of the coal are little, if at all, affected by drying it, so as to expel the contained water, but when it is heated to redness, in a close vessel, to drive off the volatile portions, it decrepitates to a considerable extent, and does not cake in the least; nor does it swell up like South Staffordshire non-caking coal, but shrinks together, as wood and lignite do when charred, and the coke left, consisting of the fixed carbon and the ash, is small in quantity (57·36 per cent. from the undried coal, according to Mr. Riley's analysis), much broken up, friable, and somewhat similar in appearance to wood charcoal. It weighs, in bulk, about 35 lbs. per cubic foot.

A lump of the coal, about a pound in weight, imbedded in sand, in a large crucible, and coked slowly for several hours, was found on turning it out, when cold, to be split to pieces.

Trials were made, without success, to produce a hard coke from the coal, by coking mixtures of it, in powder, with different proportions of caking coal and of pitch. The caking coal used was from Llyndu colliery, near Bridgend.

The following are the particulars of the experiments:—

No	Warora Coal	Caking Coal	Pitch	Results
1	100	..	5	Did not coke.
2	100	..	5	(Moistened and pressed). Did not coke.
3	100	..	10	Did not coke.
4	100	..	20	Did not coke.
5	100	..	30	Coked slightly.
6	100	..	40	Better than No. 5, but when pressed with the fingers, it crumbled to powder.
7	100	30	..	Coked slightly.
8	100	40	..	Better than No. 7.
9	100	50	..	Tolerable coke, but not fit to bear a great weight in a blast furnace.

The iron ores from the Chánda district, sent by the steam ship "Burmese" to be tested in England, are from Lohara and Pipulgaon. The following are Mr. Riley's analyses:—

	Lohara	Pipulgaon
Silica, ...	0·51	12·59
Peroxide of iron, ...	88·85	71·84
Protoxide of iron, ...	8·12	10·24
Oxide of manganese, ...	0·27	Trace.
Alumina, ...	0·94	3·03
Lime, ...	Nil.	Trace.
Magnesia, ...	0·55	0·28
Phosphoric acid, ...	0·04	Nil.
Sulphur, ...	Nil.	Trace.
Combined water, ...	0·83	2·12
Moisture, ...	0·19	0·20
Copper, ...	Nil.	Nil.
Titanic acid, ...	Nil.	Nil.
	100·30	100·30
Metallic iron, per cent., ...	68·52	58·25

In each case, the sample for analysis was taken from a lot of 4 cwt. of the ore, of average quality, crushed and mixed.

The ores are hard and compact mixtures of peroxide of iron with some magnetic oxide, and are exceptionally free from deleterious impurities; but from their hardness and compact texture they are reduced with difficulty, and will require more fuel, if smelted in a blast furnace, than if they were porous and readily reduced, as the gas passing through the furnace must contain a larger proportion of carbonic oxide. In reducing the ore, with coal and with charcoal, in closed crucibles, I found that it was acted on with comparative slowness, and Mr. Ireland mentions in a letter to me, that whereas ordinary Lancashire hæmatite is reduced to spongy iron in the Blair furnace in six hours, the Lohara and Pipulgaon ores took 10 hours.

The late Mr. David Forbes gives the following analyses of samples of ores from the same neighbourhood, examined by him some years ago for Major Lucie Smith. (Journal of the Iron and Steel Institute, 1872, page 133).

	Lohara	Dewulgaon	Goonjwai
Iron, metallic, ...	69·208	70·006	70·134
Oxygen in combination, ..	29·376	28·670	28·789
Sesquioxide of manganese, ..	0·090	0·084	0·108
Silica, ...	0·823	0·813	0·545
Alumina, ...	0·432	0·387	0·396
Lime, ...	0·054	0·026	0·055
Magnesia, ...	Trace.	Trace.	Trace.
Sulphur, ...	0·012	0·013	0·020
Phosphorus, ...	0·005	0·001	0·003
	100·000	100·000	100·000

According to these analyses, the specimens of ore examined contained more magnetic oxide than the samples analyzed by Mr. Riley; and Mr. Forbes remarks that they were all "compact admixtures of the native magnetic oxide of iron, with more or less specular oxide, (or crystallised hæmatite,) and equal in quality to the finest Swedish iron ores, so that there can be no question as to their suitability for producing the very finest iron or steel, when smelted with charcoal or with coke, provided the coal of the Chánda basin is of sufficiently good quality."

The limestone sent to England with the coal and ore is a dark grey, hard, compact stone, and contains, by Mr. Riley's analysis of an average sample—

Silica, ...	15·75	
Alumina, ...	3·52	
Protoxide of iron, ...	1·79	
Peroxide of iron, ...	Traces.	
Oxide of manganese, ...	0·15	
Lime, ...	43·17	equivalent to 77·08 per cent. of carbonate of lime.
Magnesia, ...	0·80	
Carbonic acid, ...	33·20	
Phosphoric acid, ...	0·09	
Sulphuric acid, ...	0·08	
Combined water, ...	0·91	
Moisture, ...	0·26	
	99·72	

This is not at all a rich limestone, and contains rather more phosphoric acid than is desirable in stone to be used as a flux for such high class ores as those of the Chánda district; but it is probable that stone richer in lime, and containing at the same time less phosphoric acid, may be found in the neighbourhood; as, according to Mr. Hughes (page 112), Vindhyan limestone, which is of good quality and uniform in composition, occurs within six miles of Warora, near the line of the proposed railway from Hinganghat. This contains—

Carbonates of lime and magnesia, ...	96·8
Alumina and oxide of iron, ...	1·2
Phosphoric acid, ...	Trace.
Insoluble, ...	2·0
	100·0

Mr. Ness writes, in a letter to you, dated the 25th September 1878, that rich manganese ore has been found, in any quantity, and with an outcrop 10 feet thick, at Munsir, about 12 miles north by east of Kamptee, and Mr. Riley's analysis of a sample of it is as follows:—

Silica, ...	7·75	
Peroxide of manganese, ...	48·42	= Metallic manganese, 56·02 per cent.
Protoxide of manganese, ...	32·80	
Peroxide of iron, ...	6·60	= Metallic iron, 4·62 per cent.
Alumina, ...	0·58	
Baryta, ...	0·59	
Lime, ...	Trace.	
Magnesia, ...	0·48	
Phosphoric acid, ...	0·13	
Oxides of nickel and cobalt, ..	0·30	
Combined water, ...	1·50	
Moisture, ...	0·58	
	99·73	

II.—*Blast Furnace Experiments at Warora.*

Two attempts to smelt the Chánda iron ores with Warora coal, in a blast furnace, were made by Mr. Ness, at Warora, in August and September 1875.

The furnace used was 24 feet high, 2 feet in diameter at the bottom of the hearth, 2 feet 6 inches at the top of the hearth, 6 feet 6 inches at the top of the boshes, and 3 feet 10 inches at the throat, and the hearth was 3 feet 9 inches deep. Its capacity was thus 426 cubic feet.

It was blown with three tuyeres, 2½ inches in diameter at the nozzle, and the blast was warmed to the temperature of 150° Fahr. The air at the time of the experiment was saturated with moisture, the monsoon not being over.—(Hughes, *op. cit.*, page 143.)

The ores employed were Lohara ore, already described, and brown ore from Ratnápúr, containing (page 111) about 50 per cent. of metal and 25 per cent. of earthy matter, insoluble in acids.

In both cases the experiments were conducted in the same manner; but on the first occasion the giving way of one of the tuyeres, two days after the furnace had been lighted, allowed water to get into the hearth, and cooled this to such an extent that the experiment had to be stopped.

Mr. Ness thus describes the second trial, in a report dated 12th October 1875, (Public Works Department Proceedings for May 1876):—

"The furnace, after being thoroughly dried, was filled for about three-fourths of its capacity with rough dry timber, and set fire to; on the top of this a few feet of charcoal was placed, and then regular charges of iron ore and coal, &c., were made, consisting of 1 cwt. coal to ¼ cwt. of Lohara iron ore, ¼ cwt. Ratnápúr iron ore, 20 lbs. limestone, and an occasional blank charge of coal or charcoal, this course being continued till the furnace was full; in 24 hours after lighting the furnace, the molten slag began to come down into the hearth, then blast was let on quietly, and in three hours thereafter the slag made its appearance at the cinder notch. The pressure was increased to about 1½ lbs. per square inch on the second day. During this time the slag formed and came off in larger quantities, and the hearth quickly filled with spongy iron, which would not liquify. Seeing this, I increased the blast, and added more blank charges of coal, and kept on increasing the temperature of the hearth, till I fused the firebricks, the tymp plate, and even the bottom of the hearth, still, the iron that had settled down was so mixed with the ashes of the coal that it would not liquify, and only kept accumulating, till the iron reached the top of the tuyeres, and then a stop was put to all further proceedings, till the mass was dug out, which is over a ton in weight."

In another account of the experiment, in a letter to the South Staffordshire Mill and Forge Managers' Association, Mr. Ness gives the weight of the mass of malleable iron that gathered in the hearth of the furnace as over 30 cwt., and states that towards the end of the trial the pressure of blast was increased to a little over 3 lbs. to the square inch, and its volume to about 500 cubic feet per minute.—(Hughes, page 143).

Further on, in the report above quoted (paragraph 5), Mr. Ness comments on the result of the experiment as follows:—

"My reason for taking the course I have just described being, generally, that in the aggregate the amount of foreign matter in many of the mixtures used in blast furnaces at home is not much less than is found in the mixture I expected to succeed with here; for example, it is not unusual, in England and elsewhere, to find 5 per cent. of ash in the coal and 15 per cent. of silicates in the iron ores; when the quantities required of these two to make a ton of iron are taken, we have a total of 10 per cent. from coal + 22½ from iron ore, total 32½ per cent., whereas at Warora we have 30 per cent. from the coal, and about 5 per cent. from the iron ore, or a total of 35 per cent. of foreign matter, besides what is found in the limestone used for a flux, which is similar in quantity in both cases. This excess of 2½ per cent. I fully expected to be overcome by part of the ash in the coal acting as a flux, but in practice it has not, and what has added much to the non-success of the experiment is the tendency the coal has, on entering the furnace, to decrepitate, and when it reaches the neighbourhood of the tuyeres, impoverished, to retain part of its fixed carbon, and in this semi-carbonized state is imbedded amongst the iron in the hearth, although there is evidence of an excessive heat in the hearth, from the firebricks (which are of the best quality) being melted for 6 inches in the thickness of the lining."

It is quite true, as Mr. Ness states, that in many of the mixtures commonly worked in blast furnaces, the proportion of earthy matter to the metallic iron contained in the charge is as great as in the mixture he used here; indeed, it is often much greater.

Thus, in the charge tried at Warora, the amounts of slag-forming materials and of iron are approximately as follows:—

	Quantity charged	Slag-forming materials	Iron
	Cwt.	Cwt.	Cwt.
From the coal, ...	1·00	0·139	0·008
From the Lohara iron ore,.. ..	0·25	0·008	0·171
From the Ratnápúr iron ore, ..	0·25	0·063	0·125
From the limestone,..	0·178	0·116	..
Totals, ..	..	0·326	0·304

Or, assuming that 0·304 cwt. of iron, contained by analysis in the charge, would correspond, in practice, to about 0·316 cwt. of pig iron, the amount of slag produced for 1 cwt. of pig would be about 1·03 cwt.

In the blast furnaces of the Cleveland district, the average amount of slag produced is about 1·5 to 1·6 cwt. of pig iron made.

The proportion of slag-forming materials contained in the charge has, however, comparatively little effect on the working of a blast furnace; but, in the case of the Warora experiment, several other conditions were present, which fully account for the failure to produce pig iron, whatever were the characters of the coal and ore used.

It was a mistake, in the first place, to attempt to smelt altogether with raw coal, without an admixture of coke or charcoal, in using cold or nearly cold blast; for damp air, heated to only 150° Fahr. was practically equivalent to cold blast. In England and Scotland the use of raw coal has been found to be practicable only since hot blast, heated to from 300° to 800° Fahr. or more, has been used. At the Clyde Iron Works, for instance, before 1830, when using cold blast, coke only was employed in the blast furnaces, and in South Staffordshire and many other districts, even with the help of hot blast, and in working with a coal that does not contain nearly so much volatile matter as undried Warora coal, raw coal is not used without an admixture of coke; as, if employed alone, it would cool the furnace too much.

Thus, in Staffordshire, in one instance, in 1871, the proportions used per ton of pig iron produced were—

	Cwt.
Coal, ...	35·87
Coke, ...	11·40
	47·27

and in Austria and Italy, where lignite is used in several places, in blast furnaces, it is always employed in admixture with wood charcoal.

The furnace tried at Warora was also much too low, only 24 feet high. I do not know that a blast furnace so low as this is in successful work anywhere, even for smelting porous and readily reduced ores with wood charcoal. Charcoal blast furnaces, as now constructed, vary from 26 up to 50 or 55 feet in height, and furnaces in which hard coke is the fuel used are much higher, particularly when the ore also is hard, and is reduced with comparative difficulty. Where this is the case, as in Cleveland, the blast furnaces employed are generally from 70 to 80 feet high, and furnaces varying from 90 to 100 or 105 feet in height are not uncommon. The increase of height, up to a limit of between 70 and 80 feet, is found to be attended by a marked saving in fuel.

This great height is needed to admit of the complete reduction of the ore by the ascending current of gases, and the carburetting of the reduced metal before it reaches the zone of fusion near the tuyeres; to enable the gases, as they ascend, to act on the ore as fully as possible, so that, when they pass off, they may contain the greatest possible proportion of carbonic acid; and to cool them, by contact with the materials charged.

When charcoal or soft coke is the fuel used, or when the ores smelted are friable, the practicable height of the furnace is limited by the strength of the charge to resist crushing; and in the case of charcoal furnaces, especially, the diameter is often kept small (between one-fifth and one-sixth only of the height), in many cases because a larger furnace is not needed, but also to ensure a more uniform distribution of the ascending gaseous current through the charge, and to partly support this, by friction against the sides, so as to admit of making the furnace high enough to ensure economical working, without bringing too great a crushing pressure upon the lower part of its contents.

When raw non-caking coal is used, great height in the furnace is even more advantageous than in other cases, as the ascending current of gas has not only to reduce the ore and to heat the charge, but also to drive off the volatile portion of the coal. The softness of the coke of such coal limits, however, the height of the furnaces, as they are ordinarily constructed, to between 50 and 60 feet; though Mr. Ferrie, of the Monkland Iron Works, near Glasgow, has lately succeeded in working, with raw coal, a furnace 83 feet high, by building it with the upper part divided by vertical cross walls into four sections, by friction against the sides of which the charge is partly supported, and is thus kept from crushing together too heavily.

By this alteration, aided to some extent by the heating of the upper part of the charge, by means of flues in the cross walls and in the corresponding part of the ring wall, the consumption of coal, per ton of pig iron, has been reduced from 51 cwt., the rate in ordinary Lanarkshire furnaces, 52 feet high, to about 34 cwt. This is an equal saving in fuel to that effected in the Cleveland blast furnaces, smelting Cleveland iron ore with Durham coke, by increasing the height from 48 feet to 75 or 80 feet. In this case, the effect of the increased height has been to reduce the consumption of coke, per ton of pig made, from 30 cwt. to about 22 cwt.

I am not aware that, even with the aid of hot blast, pig iron is made anywhere with raw coal as fuel, in furnaces less than 40 feet high, and it is I think questionable whether it could be made, with even the best South Staffordshire or Scotch coal, in a furnace only 24 feet high.

A third cause of failure was that the proportion of coal used was too small.

The only portion of the fuel that is of any use in a blast furnace is the fixed carbon, as the volatile part is carried away unburned in the ascending current of gases, and while it enriches these, and increases their heating power when burned outside the furnace, with a further supply of air, it only cools this, by the heat absorbed in driving it off.

In the trial at Warora, 1 cwt. of coal, containing only 0·434 cwt. of fixed carbon, was used with each charge of ½ cwt. of ore, which would yield, under suitable conditions, as above estimated, 0·316 cwt. of pig iron. This would be equal to about 27·5 cwt. of fixed carbon, in the fuel, per ton of pig, a much smaller proportion than pig iron was ever made with, in using coke and cold blast, except in furnaces 60 or 70 feet high, an absurdly small amount for so low a furnace, and actually less than is now used in smelting with raw coal, even with blast heated to about 800° Fahr., and in furnaces more than 50 feet high.

At the Clyde Iron Works, when working with cold blast, the coke from 8½ tons of coal, or about four tons of fixed carbon, was the quantity used per ton of pig iron made; in modern Lanarkshire furnaces, employing hot blast, 51 cwt. of coal, containing about 60 per cent. of fixed carbon or over 30 cwt. of carbon, is the proportion per ton of pig; and in South Staffordshire the amount used, in good modern practice, with hot blast, and in a furnace 54 feet high, was in one case, as already mentioned, 35·9 cwt. of coal and 11·4 cwt. of coke per ton of pig, or together more than 32 cwt. of fixed carbon.

In the height of the furnace employed, and the whole conduct of the experiment, the attempt to smelt the Chánda ores that was made at Warora resembled rather the mode of working formerly in use in the German stückofen and the Swedish Osmund furnace, before the blast furnace, as it is now known, had been invented.

These furnaces were from 10 to 16 feet in height, and were worked with charcoal and cold blast. After lighting the fire and partly filling the furnace with charcoal, alternate charges of fuel and ore were put in, and the blast kept on until the reduced metal had accumulated to a sufficient extent, as a malleable mass, in the hearth. The blast was then shut off, part of the furnace breast taken down, and the lump of metal removed and hammered into blooms or bars.

When the furnace was made higher, or more charcoal was used in proportion to the ore, the reduced metal was more or less carburetted, or sometimes liquid cast-iron gathered in the hearth, instead of a malleable ball.

As charcoal was the fuel used in the stückofen, the bloom of reduced iron obtained was not mixed with much ash, and could be forged at once into merchantable bars. Where coal or coke is the fuel with which the furnace is worked, this is not practicable, as the earthy ash that these leave, when burned, remains mixed with the iron, and keeps it from sticking together. In this case, a successful result is to be attained only by conducting the process in such a way as to produce liquid cast-iron and a liquid cinder, instead of a ball of solid metal, mixed with part of the ash left from the fuel.

In a modern blast furnace, the aim is always to obtain liquid cast-iron, instead of malleable metal, in the hearth, and with this object the furnace is made much higher than the stückofen, and care is taken, in working it, to keep the product of the required character, by reducing the proportion of ore if a sufficiently carburetted liquid product is not obtained.

Thus, in lighting a blast furnace, the practice is to put in comparatively little ore, in proportion to the fuel charged, until the furnace is fully hot, and pig iron of the required character has appeared at the hearth, and then to increase gradually the ratio of ore to fuel, as the furnace is found to bear it, until the maximum proportion is reached that will yield metal of the required quality.

The same watchfulness is required, so long as the furnace is at work, to keep it on a uniform quality of product; the proportion of ore to fuel, and the "rate of driving," that is the amount of blast supplied, being increased or diminished from day to day, according as the furnace, from changes in the weather or from other accidental causes, is found to be working better or worse and producing more or less grey metal.

When a blast furnace is driven too fast, so that the ore comes too quickly down into the hearth, before it has been sufficiently reduced and carburetted, the quality of the metal at once falls off, and either the rate of driving must be reduced or a larger proportion of fuel must be charged. The rate of driving that a furnace will bear is known only by trial.

This tentative mode of working, though always adopted in regular blast furnace management, is especially necessary where, as at Warora, all the conditions are strange, and it is difficult to predict what proportion of fuel to ore will be required.

If the furnace at Warora had been started with 4 or 5 cwt. of coal to each charge of ½ cwt. of ore, though it is questionable whether pig iron of any value would have been obtained in so low a furnace, with cold blast, and in using raw coal, yet the result would have been better than it was, and liquid white cast-iron, instead of a malleable ball, might very probable have been obtained.

The attempt made to melt down the mass of metal, in the hearth of the furnace, after it had collected there, necessarily failed, as malleable iron is in itself almost infusible, the cast-iron that it was sought to obtain being a fusible carburet of the metal, containing 2 to 4 per cent. of carbon and some silicon, and not the metal itself. Since the flame near the tuyeres is more or less oxidizing, its action would be rather to burn out from the metal any carbon that it might contain than to put more in.

In the normal working of a blast furnace, the carburation of the reduced iron takes place at some distance above the tuyeres, and the only action close to them is the combustion of the remaining carbon of the fuel and the melting of the already carburetted metal and of the materials forming the slag.

As the experiment at Warora was so conducted that a successful result could not have been obtained from it, whatever qualities of coal and ore had been used, its failure is not to be regarded as a proof that the production of pig iron from the minerals of the Wardha Valley is impracticable. Indeed, so far as the trial went, though it was economically a failure, its results, when analyzed, are very encouraging.

It showed that the coal, though it decrepitates when thrown into a blast furnace, does not do so to such an extent as to check the passage of the blast; that up a height of stack of 24 feet, at least, the coke in the lower part supports the weight of the mass above it very well, and does not become so crushed together as to check the blast; that sufficient fixed carbon remains in the fuel, when it comes down to the tuyeres, to produce an intense heat in the hearth; and that in a height of 24 feet only, at the rate of working adopted, the ore is thoroughly reduced and the greater part of the work of making it into pig iron is done.

III.—*Working of the Minerals in a Blast Furnace.*

The difficulty in the way of working the Chánda ores with Warora coal in a blast furnace is not that the coal contains only a small percentage of fixed carbon, in proportion to the volatile matter, together with a large amount of ash; if this were all, it would necessitate merely the use of more coal in proportion to the ore charged, or the use of coked coal, or of a mixture of coked and raw, instead of all raw coal. Nor is it that the ores are dense and difficult of reduction; they are not more dense than the well known magnetic ores of Sweden, which are smelted readily, and the trial made at Warcra showed that they could be reduced to spongy metal with moderate ease.

The real difficulty, a difficulty that may possibly prove an insuperable bar to the practical working of a blast furnace with this coal, is that the coke which it yields is soft and friable, so friable that it may be broken to pieces with the fingers, and that, though it worked well in the experimental furnace, it would crush to such an extent in a blast furnace of the size and form of those in which raw coal is commonly used, as to prevent the passage of the blast.

The trials made to produce coke from mixtures of crushed Warora coal with caking coal or with pitch, show also that a good blast furnace fuel cannot be made from it, practically, in this way.

I have endeavoured to determine, approximately, the relative resistance to crushing of the coke from South Staffordshire non-caking blast furnace coal, of the coke from Warora coal, and of wood charcoal, as affording some indication of the greatest dimensions of the blast furnace in which it would be advisable to attempt to use the coal.

The Staffordshire coal was kindly supplied by Messrs. Cochrane & Co., Woodside Iron Works, near Dudley, and is a sample of what they use regularly in their furnaces. These are 54 feet 6 inches high by 15 feet diameter of bosh; and, from the working of the coal in them, Messrs. Cochrane & Co. consider that it might be used, without difficulty, in furnaces 60 feet high.

As field-burned charcoal could not be readily obtained, that made in retorts, and used in South Wales in making "charcoal" tin-plate bars, was employed instead, but before being used in the experiments it was again heated to redness, in closed crucibles, in order to ensure that it was thoroughly charred, and to drive off any water that it might have absorbed. It was allowed to cool in the crucibles, and was turned out when cold.

The coal was in pieces that would go through a screen with meshes 2½ inches square, but not through one with meshes 2 inches square. It was thoroughly dried before weighing, and was coked in crucibles, in two cases at a low heat, and in two at a high heat.

The comparative resistance to crushing of each sample of coke and charcoal was tested by putting it, together with a heavy ball, into a hollow drum fixed on a horizontal axis, giving it in each case 50 turns, and noting to what extent it was crushed.

The whole contents of each crucible were put together into the drum, so that the proportion of small contained in the coke, after crushing, included that due to the decrepitation of the coal when coked. The drum was 24 inches in diameter by 6 inches wide, inside, and the ball used for crushing was a round stone not quite 3 lbs. in weight. Each sample was crushed at a uniform speed of 10 turns per minute, and it was then classified, by sifting it successively through sieves of 2, 1, ½, ¼ and ⅛ inch mesh, and the part retained by each sieve was weighed.

The following are the results of the experiments:—

Warora Coal.

	Coked at Low Heat		Coked at High Heat	
	Grains		Grains	
Weight charged into crucible, ..	35,000		35,000	
Weight out, ...	22,410		23,450	
Weights retained (after crushing)—		Per cent.		Per cent.
By 2-in. sieve, ...	None.	..	None.	..
" 1 "	3,000	13·5	5,510	23·6
" ½ "	10,820	48·6	8,750	37·5
" ¼ "	3,580	16·1	4,060	17·4
" ⅛ "	1,620	7·2	1,500	6·4
Fine, ...	3,250	14·6	3,530	15·1
	22,270	100·0	23,350	100·0
Loss, ...	140		100	
	22,410		23,450	

Staffordshire Coal.

	Coked at Low Heat		Coked at High Heat	
	Grains		Grains	
Weight charged into crucible, ..	35,000		35,000	
Weight out, ...	22,350		21,690	
Weights retained (after crushing)—		Per cent.		Per cent.
By 2-in sieve, ...	820	3·8	None.	..
" 1 "	4,350	19·7	1,230	5·7
" ½ "	12,290	55·8	14,760	68·6
" ¼ "	1,380	6·3	2,490	11·6
" ⅛ "	1,080	4·9	850	3·9
Fine, ...	2,100	9·5	2,190	10·2
	22,020	100·0	21,520	100·0
Loss, ...	330		170	
	22,350		21,690	

Wood Charcoal.

	Heated to Low Heat		Heated to High Heat	
	Grains		Grains	
Weight charged into crucible, ..	10,500		10,500	
Weight out, ...	7,470		7,460	
Weights retained (after crushing)—		Per cent.		Per cent.
By 2-in. sieve, ...	None.	..	None.	..
„ 1 „	1,200	15·6	1,360	18·4
„ ½ „	4,500	58·3	3,860	52·1
„ ¼ „	1,170	15·2	1,450	19·6
„ ⅛ „	260	3·4	230	3·1
Fine, ...	580	7·5	500	6·8
	7,710	100·0	7,400	100·0
Error (excess).. ..	240		Loss 60	
	7,470		7,460	

The sums of the percentages of each fuel that were retained, after crushing, by the 2-inch, 1-inch, and ½-inch sieves, taken together, are :—

	Low Heat	High Heat	Mean
Warora coke, ...	62·1	61·1	61·6
South Staffordshire coke, ...	79·3	74·3	76·8
Wood charcoal, ...	73·9	70·5	72·2

If the percentage of each fuel that was retained by the ¼-inch sieve is included in the calculation, the charcoal takes a still higher position, but Warora coke remains the most friable of the three.

Thus, the sums of the percentages of the fuels that were retained by the 2-inch, 1-inch, ½-inch, and ¼-inch sieves, taken together, are as follow :—

	Low Heat	High Heat	Mean
Warora coke, ...	78·2	78·5	78·35
South Staffordshire coke, ...	85·6	85·9	85·75
Wood charcoal, ...	89·1	90·1	89·6

The coke from South Staffordshire coal and wood charcoal are thus much on an equality, in their resistance to crushing, as tested in the revolving drum. The coke made, on the one hand, a larger percentage of fine, that would pass through a ⅛-inch sieve, than the charcoal; 9·85 per cent., on the average, against 7·15 per cent.; but it yielded, on the other, a greater proportion of pieces of the larger sizes.

The greater percentage of large that the coke yields, when crushed by an equal weight, gives it an advantage in the blast furnace; and if they were of the same density it would admit of the furnaces being higher for South Staffordshire coal than for charcoal.

The greater lightness, however, of charcoal than of coke renders the pressure of a column of mixed charcoal and ore less than that of an equally high column of coke and ore, and to a great extent redresses the inequality; so that, in practice, coal furnaces and charcoal furnaces work well when of nearly equal maximum height.

Blast furnaces, working coal, are generally 50 to 55 feet high by 12 to 15 feet in diameter of bosh, and the largest charcoal furnaces are of equal height, and about 10 feet in diameter at the boshes.

A furnace using Warora coal, and more than 25 or 30 feet high, would probably choke up, from the crushing together of the fuel, if it were made as wide as coal furnaces generally are; and since 40 feet is about the least height of a furnace that will work satisfactorily, burning coke or coal, the ordinary Scotch or Staffordshire form of furnace cannot be used.

A furnace similar to that built by Mr. Ferrie, and already referred to, may, however, be found suitable, and it is in this direction that any further blast furnace experiments with Warora coal should be made.

Mr. Ferrie, using the same coal and ore as those ordinarily smelted, in the Glasgow district, in furnaces 52 feet high and 15 to 18 feet in diameter at the boshes, and that cannot be worked in higher furnaces, of the common form, on account of the crushing of the charge, has succeeded in smelting in a furnace 83 feet high, by dividing 30 feet of the upper part of the shaft, by vertical cross walls, into four sections, by friction against the sides of which the weight of the charge is partly supported. Mr. Ferrie makes flues, also, in these cross walls and in the corresponding outside walls of the furnace, in which part of the escaping gas is burned; and by the two arrangements jointly, the saving effected amounts to 19 cwt. of coal per ton of pig iron made.—(I. L. Bell, Chemical Phenomena of Iron Smelting, page 309.) I send with this a copy of the Journal of the Iron and Steel Institute, for May 1871, in which Mr. Ferrie's furnace is described.

Ferrie's furnace seems to have been introduced more successfully in the United States of America than at home. At the works of the Etna Iron Company, at Ironton, Ohio, U. S. A., there are two of these furnaces, 87 feet 6 inches high, working with blast heated in Whitwell's firebrick hot blast stoves. An account of the blowing in of the first furnace is contained in "Iron" for 1st April 1876, page 427, and notices of their working are given in the Foreign Reports to the Iron and Steel Institute, No. 1, 1876, page 247, and No. 2, 1877, page 7.

They appear to work well, but according to the late Mr. Whitwell (Journal of the Iron and Steel Institute, 1878, page 203), the coal used is found to be too soft to stand the crushing action of so high a column of materials, and a small proportion of coke is used with it, to keep the furnace open. In Staffordshire, as Mr. Whitwell states (*loc. cit.*) a furnace of this type is also worked, but the heating flues in the walls are not used.

For working with Warora coal, a furnace so high as that built by Mr. Ferrie, at Monkland, would, of course, be unsuitable, but it is possible that this fuel may be found to work, satisfactorily, in a much lower furnace of similar form. Even in a furnace 40 feet high, the working will be economical only if very hot blast is used, and it will be a matter for trial whether or not the coal should be partly or wholly coked before it is charged.

The experiment may be tried, with least expense, by altering the existing furnace at Warora, increasing its height to 40 feet and reducing its greatest diameter to 5 feet. In the Ferrie furnace, at the Monkland Works, the mean cross section of each retort is about 28·25 square feet, and its mean circumference is 21·4 feet; the same ratio of circumference to area as in a circle 5·28 feet in diameter.

The depth of the hearth, below the tuyeres, may also, I think, be made 6 or 9 inches less, with advantage, in so small a furnace. I add a tracing, showing the alterations I would suggest.

With the altered furnace, and using the same blowing and blast warming apparatus as before, the iron smelting experiment should then be repeated, under the charge of an experienced furnace manager, one used, if possible, to smelting with raw coal; and if liquid pig iron of any kind is obtained, and the furnace works regularly, the experiment may be considered successful.

Trials should be made both with raw coal, as before, and with coked coal, coked in heaps on the Staffordshire plan. This mode of coking is described and illustrated in the first volume of Dr. Percy's Metallurgy.

It is simple, and involves little outlay for plant. The coke should be screened, before use, and only so much as is retained by a 1-inch or 1½-inch riddle should be charged into the furnace.

The iron produced will probably be white, full of sulphur, and useless for any purpose, and it will be made only at the cost of an enormous expenditure of coal; but if it can be made at all, if the coke is sufficiently hard to render the working of the furnace possible, the use of a larger furnace, on Ferrie's plan, divided by internal cross walls, so as to offer as much resistance, from friction, to the descent of the charge as is afforded in the experimental furnace, and the use of highly heated blast, will reduce the consumption of fuel to a reasonable amount, and will make the metal good and serviceable.

Mr. Bell has pointed out that the effect of hot blast, in promoting economy of fuel in a blast furnace, is precisely the same as that of increasing the height of the furnace. Thus, at Lilleshall, by increasing the height of the cold blast furnaces from 53 to 71 feet, the consumption of coke, in smelting 43 per cent. ores, has been reduced from 40 cwt. to 27 or 28 cwt. per ton of pig iron made; as small a quantity of coke as would have been required in the old furnaces, 53 feet high, if they had been blown with air heated to between 800° and 900° Fahr. (Chemical Phenomena of Iron Smelting, page 356.)

While highly heated blast may replace height of furnace, without affecting the consumption of fuel, the economy that may be attained by these two agencies, jointly, is limited by the greater or less facility with which the ore is reduced, so that, while very hot blast is of doubtful advantage in furnaces so high as those of the Cleveland district, it effects a remarkable economy and a great improvement in the metal produced, in the case of furnaces which, owing to the softness of the fuel or the ore, cannot be made very high, and for such furnaces the blast cannot be too hot. Thus, at Warora, if it is found that by adopting Mr. Ferrie's plan, a furnace, 40 feet high can be worked, it will be advantageous to use blast heated to the highest possible temperature. The heating of the blast is effected, without cost, by the combustion of the waste gases from the top of the furnace.

The hottest blast is that produced by Cowper's or Whitwell's firebrick stoves. Of these the Cowper stove is theoretically the best, and it is the less costly of the two, and occupies less ground space. It was not, however, easily cleaned from dust, as it was first designed, and Whitwell's modification was introduced to overcome the difficulty; but it is claimed that, by recent improvements in their construction, Cowper's stoves may now be cleaned with ease, so that Whitwell's form has no longer any advantage. I enclose a pamphlet descriptive of Cowper's stoves, and some other papers relating to them.

Messrs. Cochrane & Co., smelting a refractory mixture of ores, in their furnace 54 feet 6 inches high, and with blast heated to between 1,400° and 1,500° Fahr. by these stoves, use—

Staffordshire coal, ...	19¼ cwt.
Coke from ditto., ...	14 „

per ton of pig iron made. Assuming that the coke contains 90 per cent. and the coal about 60 per cent. of fixed carbon, this is equal to 24·3 cwt. of carbon per ton of pig. In 1871, when the blast was heated in cast-iron stoves, to about 800° Fahr. only, the consumption of fuel, per ton of pig iron made, was—

Staffordshire coal, ...	35·87 cwt.
Coke from ditto., ...	11·40 „

equal to about 31·8 cwt. of carbon per ton.

The principal difficulty in the way of producing good pig iron, for steel making, with Warora coal as fuel, if blast furnaces can be worked, will be that the coal contains rather a high percentage of sulphur, and that the pig iron will be liable to take up sulphur from it.

This may be prevented in several ways, and I do not anticipate that it will be a cause of any serious trouble.

The use of the very hot blast already advocated, and working the furnace with sufficient fuel to make No. 1 or No. 2 grey pig iron, will be one safeguard. It is well known, that in any blast furnace in which sulphur is contained in the charge, it may be kept to a great extent out of the iron by working the furnace hot and making the metal very grey. If, from any cause, such as greater dampness of the air or of the materials, the furnace happens to make less grey or white iron, the metal is much more contaminated with sulphur, and the less grey it is the more sulphur it contains. White iron, from the same furnace and the same charge, contains often more than 20 times as much sulphur as No. 1 grey iron.

Another precaution that should be adopted, to keep the metal free from sulphur, is to add as much limestone to the charge as is consistent with keeping the slag sufficiently liquid. To admit of working with a very basic and therefore a comparatively refractory slag, blast as hot as possible is again advantageous, as it keeps the hearth of the furnace at a higher heat.

It is difficult to estimate, exactly, how much Warora coal will be needed in the blast furnace, if it can be worked, but assuming that 35 cwt. of fixed carbon, or 80·6 cwt. of coal, will be required per ton of No. 1 or No. 2 grey pig iron made, and that the ores used will be, as in the former trial, equal parts of Lohara and of Ratnápúr ore, the ratio of silica to alumina, in the earthy matter of the charge, will be as 100 to 41·5, and with this proportion of alumina, a slag containing 48·5 per cent. of lime will be sufficiently fluid to run from a hot-blast furnace. To make such a slag, if the pure Vindhyan limestone is used, of which Mr. Hughes gives an analysis, 25·1 cwt. of it will be required, and the materials to be used per ton of pig iron made will be—

	Cwt.
Coal, ...	80·6
Lohara iron ore, ...	16·2
Ratnápúr iron ore, ...	16·2
Vindhyan limestone, ...	25·1

With these proportions, the slag per ton of pig will be about 28·8 cwt., or rather less than in average Cleveland practice. In the experimental cold-blast furnace, little more than half this amount of limestone should be used, in proportion to the coal, or the slag will not be sufficiently liquid.

Some of the rich manganese ore that has been found near Kamptee may also be added to the charge, with advantage, if the metal produced is found to contain too much sulphur. Spiegel-eisen, a pig iron containing from 5 to 20 per cent. of manganese, though smelted with coke, contains no sulphur; the addition of sufficient manganiferous ore to a blast furnace charge to put 2 per cent. of manganese into the metal reduces the sulphur contained in it from 0·2 or 0·3 per cent. to 0·05 or 0·08 per cent.; and pig iron containing 3 per cent. of manganese never contains more than a trace of sulphur.

If pig iron containing less than 0·1 per cent. of sulphur can be produced, the making of it into steel will present no difficulty. It may be treated by either the Bessemer or the open hearth process. I send with this a copy of a paper on steel making that I read some time ago before the Institution of Civil Engineers, in which both are described.

The Bessemer process is preferable, in working from pig iron, for making steel suitable for rails, tyres, and plates, where the production required is large; but it cannot be carried out on a small scale; and thus, for a small output, the plant required is expensive, and the open hearth or Siemens' process involves less outlay. The Siemens' process is also the better fitted for making steel of the higher qualities. The cost, in England, of the open hearth plant required to convert 100 tons of pig iron into steel ingots, per week, would be, including building and all accessories, about £5,000.

In making steel by either the Bessemer or the open hearth process, from 0·5 to 1 per cent. of manganese, in the form of spiegel-eisen or ferro-manganese, must be added to the metal. If steel making becomes established at Warora, this manganese alloy may be made, in a blast furnace or cupola, on the spot, but at the first it had better be imported from Europe, and rich ferro-manganese, containing 50 or 60 per cent. of the metal, may be found the most advantageous, on account of the expense of carriage, as a small quantity only, 2 or 3 per cent. of the steel made, will be required.

IV.—*Working of the Minerals by Direct Processes.*

Mr. Ness, in his Report of the 12th October 1875, after giving the account above quoted of the trial he had made to smelt the Chánda ores with Warora coal in a blast furnace, a trial which he regarded as proving, conclusively, that it would be impracticable to work these materials in that way, mentions the Blair process of reducing rich iron ores to spongy metallic iron, and subsequently treating this for the production of steel, without making pig iron at all, and suggests that this mode of working may be found suitable for the treatment of the Wardha Valley minerals.

In consequence of this report, samples of Lohara and Pipulgaon iron ores, of Warora coal, and of limestone, were sent to England, for trial by different modes of direct treatment.

Mr. Ness superintended the experiments, and gives an account of them in another Report, dated Glasgow, 5th January 1878. In this, he expresses a decided opinion in favour of the Blair process, and advises the erection, at Warora, of a reducing or sponge making furnace on this plan, and of a crucible steel-melting furnace, for the melting of the sponge into ingots of tool steel.

The Blair process is, certainly, one of the most promising of the many that have been suggested for the production of malleable iron or steel from the ore, without first making pig iron; but, like nearly all such processes, nearly all of them, at least, in which coal can be used as fuel, it has the serious drawback that, so far as I have been able to learn, it is nowhere practically and commercially at work.

Mr. Blair carried it on, for some time, in works near Pittsburg, Pennsylvania, U. S. A., but these were closed three years ago, and since then it has not, I believe, been worked anywhere, except on an experimental scale by Mr. J. Ireland, of Manchester, who is joint patentee, with Mr. Blair, of some modifications of the process and forms of the apparatus.

The Chenot process is the only direct mode of treating iron ores, in which coal may be the fuel employed, that is known to be in practical use. This method was first brought before the public in 1851, and a great future was expected for it, but it has not in most cases been found to compete advantageously with the methods of manufacture in common use, and it is now in operation in two works only, at Baracaldo, near Bilbao, in Spain, and at Clichy-la-Garenne, near Paris.

The process is described, at considerable length, in Dr. Percy's Metallurgy, and an account of it, as practised at Clichy, is given in the "Révue Hebdomadaire de Chimie Scientifique" for September 7th, 1871. It consists, essentially, in exposing the ore, in pieces of about two cubic inches in volume and mixed with a fifth of its weight of wood charcoal, to a red heat in vertical retorts. The retorts used, in one instance, of which particulars are given by Percy, were 28 feet high, and 6 feet 7 inches long by 20 inches wide. Each held a charge of 2 tons of ore, with a corresponding amount of charcoal, and the reduction to sponge required an exposure of the mass to heat for three days. In some instances, where charcoal was abundant, the reduction was effected by the direct action of a current of hot carbonic oxide, driven through the mass of ore, and at once heating and reducing it, instead of by heat transmitted to the mixed ore and charcoal through the walls of a retort.

Mr. Sandberg studied the process, very fully, in 1862, and reported on it to the Swedish Board of Ironmasters, at Stockholm. He states that the reduction of the ore was never uniform or complete, and that it was necessary, in all cases, to pick over the sponge, separating the imperfectly reduced portions, to be treated again. The reduced sponge was generally "sunk" into balls in a charcoal fire, and then hammered or rolled into bars. 1·6 ton of sponge, containing 93·6 per cent. of iron, yielded 1 ton of finished bars, with a consumption of 0·86 ton of charcoal in making the blooms, and 1 ton of coal in reheating these before forming them into bars. At Baracaldo, in 1862, bar iron was made in three different ways,—by the Chenot process, by puddling charcoal pig iron, and by puddling coke pig iron, and the costs of the three qualities were respectively 500, 450, and 400 francs per ton.

The difference between Mr. Blair's process and that of Chenot is in the mode of heating the mixture of ore and carbon charged into the retorts. Mr. Blair claims to have discovered that the irregular and slow reduction of such mixtures is due simply to their low conducting power for heat, and that if the mass is once heated up, throughout, to uniform redness, and merely kept from cooling, reduction will take place regularly through it, without any absorption of heat, so that no additional supply of heat will be required. This is contrary to the view of most metallurgists, who consider that in the reduction of iron ore by solid carbon a constant absorption of and demand for heat go on, but the results obtained by Mr. Blair and Mr. Ireland seem to establish it beyond question, and the Blair process may be regarded as a substantial advance on that of Chenot, so far as the production of reduced spongy iron is concerned.

In Mr. Blair's first form of furnace, patented in England in 1872 (No. 1,795), the initial heating of the ore and carbon was effected by introducing the charge into the retort through an annular space, heated inside and outside, in which no part of the charge was more than three inches distant from the heating surface. "Each reducing furnace consisted of a group of three vertical retorts, each retort being 3 feet in internal diameter, and about 28 feet high, surrounded by an outer casing of brickwork, leaving a combustion chamber between the inside of the brickwork and the outside of the retorts. The retorts and outside brickwork stood upon a cast-iron entablature, supported on columns 12 feet from the ground; below the entablature, and forming a continuation of each retort, were wrought-iron cylinders, each surrounded with a water jacket, for more quickly cooling the iron sponge, and having at the lower extremity a sliding sleeve for discharging it. In the top of each retort a cast-iron pipe or thimble, 2 feet in diameter, and about 6 feet long, was inserted, leaving an annulus of 6 inches between it and the inside of the retort.

"The retorts were heated externally, by gas jets, the air for combustion being supplied through apertures immediately above each jet. When the retorts were thoroughly heated, and all in working order, the gas generated from the ore under reduction ascended up the inside of the pipe inserted in the top of the retort, and on meeting with air flamed, and so heated the pipe. The ore and carbonaceous matter were fed into the retort down the 6-inch annulus, between the retort and pipe, and forming a narrow column heated on both sides, were thoroughly heated up before reaching the wide retort below." (J. Ireland, "On the Manufacture of Iron Sponge by the Blair process," Journal of the Iron and Steel Institute, 1878, page 47).

This form of furnace seems to be referred to in paragraph 9 of Mr. Ness's Report of the 5th January 1878, but nothing like it is shown in the accompanying drawings.

In it, the reduction of the ore to spongy metal was effected in about 30 hours.

Subsequently Mr. Blair found that, by the addition to the charge of about five per cent. of lime, or of any alkali, the reduction was so much quickened that an ore which formerly required 30 hours to bring it to the metallic state could be perfectly reduced in 6 hours.

To take full advantage, however, of this possibility of more rapid reduction, it was necessary to devise some means of heating up the charge more quickly; and this Mr. Blair proposes to do, where fuel sufficiently free from sulphur is to be had, by forcing a current of hot carbonic oxide through the mass, much in the same way as in the Chenot direct heating arrangement, except that Mr. Blair adds carbon and lime to the charge of ore, instead of using ore alone. Such a furnace, according to Mr. Ireland (*op. cit.*, page 50), with a retort 5 feet in diameter in the upper and 6 feet 6 inches in the lower part, by 16 feet high, will reduce 200 tons of ore to the metallic state weekly.

As charcoal is not to be had as fuel at Warora, and the Warora coal contains a good deal of sulphur, a furnace such as that just mentioned would not be suitable there, and "therefore," as Mr. Ireland writes in the paper already quoted (page 51), "the old form of furnace must be used, in which the heat is transmitted through the retort; but here, again, some different arrangement must be made to heat up the ore more quickly. The writer ultimately concluded to abandon the inserted pipe or thimble, and divide this part of the retort into a number of smaller ones, so as to present as small a column of materials to the action of the heat as possible. A small furnace, some 21 feet in height over all, was erected on this principle, with a reducing retort about 18 inches diameter and 10 feet 6 inches high, and a cast-iron pipe on the top, $8\frac{1}{2}$ inches diameter, to heat up the ore. This furnace works well, and has been in constant operation since September last. Some 20 tons of the Indian ore have been operated on, and iron sponge of uniform and excellent quality produced, part of which has been since made into first-class tool steel, and some of it melted in a cupola into pig metal......... Various other ores have been reduced in this furnace with the same uniform result.

"Though of small dimensions, this reducing furnace is on the principle proposed for working with transmitted heat, and, in furnaces of larger diameter, the number of small heating retorts, placed on the top of the larger or reducing one, will be increased, as the diameter of the latter increases; thus, a reducing furnace of 3 feet diameter will have four small retorts above it, and 5 feet diameter will have seven. The top of the large retort is arched over, against a circular key-brick, having a hole through its centre, one of the small retorts standing on the top of it. The remainder are placed round, each resting on two of the arches, so that the ore, &c., when heated, falls down between the arches into the large retort below. The spaces between the arches being almost square, and the small retorts round, a space is left at each corner, through which the gas generated from the ore under reduction can escape into the combustion chamber round the small retorts, thus helping to heat them. To cool the iron sponge, as quickly as possible, after reduction, it is split into three or more columns (according to the size of the furnace) in the wrought-iron cylinders below, each cylinder being surrounded by a water jacket, through which a slow current of cold water is passed, and on being discharged from the mouth pieces, is sufficiently cool that oxidation does not take place. A reducing furnace of this description, 5 feet diameter and 40 feet high, will reduce 60 to 70 tons of ore to a metallic state weekly, and the cost is about £600."

No mention is made of this construction in Mr. Ness's Report; but it, or something like it,—some arrangement in which the ore and the gases from the fuel are kept apart, while, at the same time, a rapid and thorough initial heating of the charge is provided for,—will probably be the best adapted for treating the materials of the district, if the Blair process is employed.

The density of a sample sent to me, from the India Stores, of iron sponge reduced by the Blair process from Lohara and Pipulgaon ores, is 102 or 103 lbs. per cubic foot.

In the production of metallic sponge, by Mr. Ireland, from these ores, Warora coal was the reducing agent used, and the reduced metal contained in consequence a very sensible amount of sulphur. As it would be difficult to obtain an average sample of the sponge, for analysis, on account of its toughness, the proportion of sulphur that it contains may be assumed to be the same as that in two samples of steel made by melting it, in crucibles, with wood charcoal.

These were marked, respectively, F and G (*see* Mr. Ness's Report, of 5th January 1878, paragraphs 22 and 29), and contained the following amounts of sulphur:—

	Per cent.
In the sample F, ...	0·327
" " G, ...	0·133
Mean, ...	0·230

This is a proportion which, though admissible in tool steel, would render larger ingots of soft steel, such as that for rails, tyres, plates, &c., unforgeable, and if the sulphur cannot in some way be kept out, it will be necessary either to abandon the hope of being able to make rail or plate steel by the Blair process from these materials, or to use wood charcoal, with the ore, in the reducing retorts.

Some experiments that I have made in the matter lead me, however, to believe that by the use of lime, mixed with the ore, in the retorts, in rather larger quantity than Mr. Blair recommends, the proportion of sulphur that the reduced metal takes up may be kept so small as to be harmless.

Thus, when Lohara ore was reduced in a crucible, with an excess of Warora coal, and without any addition of lime, the resulting spongy metal contained in one trial 0·611, and in a second 0·65, per cent. of sulphur.

When 10 per cent. of slacked lime was added to the ore, the reduced metal, brushed clean from adhering dust, contained only 0·082 per cent. of sulphur in one experiment, and 0·10 per cent. in a second, or on the average 0·091 per cent., an almost harmless amount, as rail steel containing even 0·15 per cent. of sulphur is forgeable, if it contains also 0·8 or 1 per cent. of manganese.

In another trial, with the lime in small pieces, about the size of mustard seed, and free from dust, in using 10 per cent. of lime, the reduced metal contained 0·109 per cent. of sulphur, and with 15 per cent. of lime it contained only 0·054 per cent.

When Lohara ore was reduced with wood charcoal, the sponge contained only traces of sulphur.

These results correspond well with the analyses, above quoted, of steel melted from sponge made by the Blair process, with the addition of 5 per cent. of lime to the ore. This contained 0·23 per cent. of sulphur. I found that the ore reduced by Warora coal, without lime, contained more than 0·6 per cent. of sulphur, that with 10 per cent. of lime it contained about 0·1 per cent., and that with 15 per cent. of lime it contained only 0·054 per cent.

In practice, the ore would be mixed with coal and with the necessary proportion of lime, 10 or 15 per cent. in powder, or in very small pieces, and passed through the reducing retort, and then, as the lime, after reduction, will contain nearly all the sulphur that was present in the coal, it should be separated, as completely as possible, by passing the spongy metal through a revolving screen, in which the friction of the pieces against each other will knock off the greater part of it. Even if some lime containing sulphur is left in the sponge, the sulphur will probably pass, in the subsequent treatment, with the lime into the slag, and will not affect the metal.

It may be assumed, from the above, that good iron sponge can be made practically and cheaply at Warora, from the Chánda ores; but, even granting this, the treatment of it, for the production of merchantable iron or steel, remains still a matter of difficulty.

Chenot's method of "sinking" the sponge into balls, in a charcoal fire is inapplicable, as charcoal is not to be had at a sufficiently low price, and, as Mr. Ness found, (Report, 12th October 1875, para. 5), the use of coal instead of charcoal, in admixture with the ore, is impracticable, on account of the large amount of ash that it contains.

It is possible that compressed blocks of sponge from the richer ores, alone or mixed with suitable fluxes, may be heated in a welding furnace, and worked into blooms sufficiently clean to make merchant iron; or the sponge may be balled up in a bath of melted oxide of iron, or on a cinder bottom, in a puddling furnace, and so worked into blooms and bars. Mr. Blair employed this latter plan, to some extent, at Pittsburg. He balled up the sponge, in some cases, in an auxiliary furnace, before charging it into the melting furnace, and states that when the balling is done in a gas furnace, very little of the sponge is oxidized.

The quality of the metal obtained, and the amount of waste, in these modes of working, must be determined by trial, and, in the event of the failure of all such plans, the sponge may still be made into steel.

By Chenot's mode of working, steel is made from the sponge by fusion in crucibles. The sponge is crushed, mixed with charcoal or other carburetting materials, compressed into little cylindrical blocks, and melted in the ordinary way.

Fusion in crucibles is also the mode of treating the sponge proposed by Mr. Ness for adoption at Warora. In the experiments mentioned in his Report, the sponge, as it came from the reducing retort, and without compression, was charged into the crucibles, together with a little charcoal, and melted down.

This is an expensive mode of working, more especially as the sponge, even when compressed, is more bulky than cut up bar iron or broken blister steel, so that while the expenses of crucibles, fuel, and labour are much the same as in melting compact metal, the outturn of the furnace is less. It is a process, also, that is adapted only for making small ingots of hard steel, such as is used for tools. When softer steel is made, the expenses of working are much increased, owing to the higher temperature that is required to melt it, and the consequent increase in the consumption of fuel, increased wear of the furnace and the pots, and decreased output; and the collection into one or two large ingots of the small quantities of metal melted in a number of pots is also troublesome and expensive.

Mr. Blair, in his works at Pittsburg, adopted the open hearth or Siemens-Martin method of melting the sponge into ingots. This is the only practicable mode of making from it the softer and cheaper qualities of steel, such as those used for bridge work, and for rails, tyres, plates, &c., but, as it was carried out by him, it has the disadvantage that a considerable proportion of pig iron is required, together with the sponge, and that the waste from oxidation is great.

Mr. Blair used pig iron to form the initial bath, and the sponge was thrown into it, either cold, in loose pieces as it came from the reducing furnace, compressed into blooms 6 inches in diameter by 12 to 18 inches long, pressed into blooms or "tar plugs" with 8 per cent. of coal tar, or finally heated to welding on the cinder bottom of a puddling furnace, balled up, and charged into the melting furnace in a form like that of unhammered puddled balls.

The tar plugs and most of the blooms were heated to redness in an auxiliary furnace, and charged hot into the melting furnace; the loose sponge was thrown in cold.

The tar plugs were used to carburet the bath, and reduce the proportion of pig iron needed, and it was Mr. Blair's object to dispense in this way with pig iron, if possible, altogether, but I am not aware that he succeeded in doing so.

Mr. I. L. Bell, in the account he gave, in a paper read before the Iron and Steel Institute, of his visit to the United States, in 1874, commented on the Blair process somewhat unfairly, as those interested in it thought, remarking more especially on the amount of waste incurred in melting the sponge, and the correspondence that ensued contains some of the most reliable information that has been published as to its working.

In one series of eleven casts, at Mr. Blair's works, the materials used were:—

	Lbs.	Lbs.	Per cent.	
Pig iron, ...	..	23,816	30·8	
Scrap steel, ...	..	14,161	18·3	
Tar plugs, ...	13,255			17·1
Hot sponge, ...	10,500	31,871	41·2	13·6
Cold sponge, ...	8,116			10·5
Spiegel-eisen, ...	..	7,531	9·7	
		77,379	100·0	

Deducting 8 per cent. for tar from the 13,255 lbs. of tar plugs, say 1,060 lbs., leaves for the gross quantity of sponge 30,811 lbs.; and again deducting one-eighth from this, for earthy matter (silica, alumina, &c.,) say 3,852 lbs., the actual metallic constituents of the 11 charges stand as follows:—

	Lbs.	Percentage of charge	Percentage of yield
Pig iron (as before), ...	23,816	32·9	38·5
Scrap steel, ...	14,161	19·5	22·9
Iron in sponge, ...	26,959	37·2	43·6
Spiegel-eisen, ...	7,531	10·4	12·2
	72,467	100·0	
Steel produced (ingots and scrap),..	61,870		
Loss, ...	10,597 equal to 14·6 per cent. of the charge.		

In two charges of sponge, made by the Blair process by Mr. Ireland, that were melted to steel for rails at the Panteg Steel Works, Monmouthshire, in May 1875, the results were very similar. The sponge was thrown loose into the bath of pig iron, without any preliminary treatment. I am indebted for the particulars of these to the Managing Director of the Company. They are as follows, the weights being reduced, as in the American example, to pounds:—

Number of Charge	117 C. Lbs.	118 C. Lbs.
No. 3, Hæmatite pig, ...	2,779	9,254
Sponge, ...	3,052	9,824
Spiegel-eisen,..	416	1,703
Total charge, ..	6,247	20,781
Steel produced (ingots and scrap),..	4,349 lbs.	16,037 lbs.
Carbon, ...	0·36 per cent.	0·57 per cent.

Assuming, as before, that the sponge contained one-eighth of its weight of earthy matter, the corrected weights and percentages will be as under:—

Charge, 117 C.	Lbs.	Percentage of charge	Percentage of yield
Pig iron,..	2,779	47·4	63·9
Iron in sponge, ...	2,670	45·5	61·4
Spiegel-eisen, ...	416	7·1	9·6
Total metallic charge, ..	5,865	100·0	
Yield, ...	4,349		
Loss, ...	1,516 equal to 25·8 per cent. of the charge.		

Charge, 118 C.	Lbs.	Percentage of charge	Percentage of yield
Pig iron, ...	9,254	47·3	57·7
Iron in sponge, ...	8,596	44·0	53·6
Spiegel-eisen, ...	1,703	8·7	10·6
Total metallic charge, ..	19,553	100·0	
Yield, ...	16,037		
Loss, ...	3,516 equal to 18·0 per cent. of the charge.		

In Mr. Blair's practice, 50·7 tons of pig iron and spiegel-eisen, together, were used, in addition to sponge, for each 100 tons of steel ingots and scrap made, or estimating the yield of merchantable steel at 80 per cent. of the ingots, about 65 tons of pig and spiegel-eisen would be needed, for every 100 tons of finished steel produced.

The results at Panteg were still worse, the proportion of pig iron and spiegel-eisen used there having been about 70 tons, for 100 tons of ingots made, or nearly a ton of pig iron for each ton of merchantable steel turned out.

These proportions of pig iron used to steel turned out are not, it is true, the lowest that can be counted on, as, in the charges at Mr. Blair's works, part only of the sponge used was in the form of tar plugs, and part was charged cold and without compression. The melting furnace used was also defective in design, and inferior in working to those now employed. At Panteg, also, the sponge was all thrown loose and cold into the bath, and it had, I believe, been in stock for some time, and may have become partly oxidized.

Still it is evident that the success at Warora of the open hearth Blair process, as it was worked at Pittsburg, is very uncertain, as it can be employed there only if pig iron of suitable quality can be made on the spot, or if the use of it can be altogether or almost altogether dispensed with.

Mr. Ireland proposes to melt the sponge first, in a cupola, to white cast-iron, with coked Warora coal, and to charge this into the open hearth furnace in a liquid state, and if this can be done, it will obviate the difficulties of the process most satisfactorily. I fear, however, that unless charcoal can be used in the cupola, the plan, as proposed, will be found impracticable.

The avidity with which melted steel or melted white cast-iron takes up sulphur is so great that, if coke is the fuel used, the metal will be so contaminated with sulphur as to be useless.

White pig iron, from a blast furnace in which coke is used, contains, as already mentioned, a much greater proportion of sulphur than grey iron from the same furnace; in melting grey pig in a cupola, for the open hearth steel process, with coke, if the tuyeres are adjusted so as to burn out some of the carbon and silicon from the metal, and make it white, it at once takes up between 0·2 and 0·3 per cent. of sulphur; and in crucible steel-melting, with coke, in which, when a pot bursts, the steel runs through the fire into the ashpit below, the runnings, in their momentary passage through the fuel, take up so much sulphur as to render them almost worthless.

A trial of the plan, carried out at Woolwich Arsenal, and described in paragraphs 30, 31, and 32 of Mr. Ness's Report of 5th January 1878, shows the same result. Sponge, reduced from the Chánda ores, was melted in a foundry cupola with English coke, and tapped out as white cast-iron. Steel made from a portion of this metal was quite unforgeable, and Mr. Riley, on analyzing some of it, found that it contained, as a mean of two determinations, 2·58 per cent. of sulphur. In another sample, supposed to be part of the same charge, Mr. Riley found only 0·344 per cent. of sulphur; but this, though still more than twice as much as is admissible, under any circumstances, in mild steel, is so much less than I should have expected, and so much less than was found in the former sample, that I cannot but think that there has been an error in the sampling or in the marking.

It is possible that, by using very hot blast in the cupola, instead of cold air, and by charging as much lime with the sponge as is found to be consistent with retaining the slag of such a composition as to be sufficiently liquid, or by charging manganese ore with it, the sulphur may be kept out of the metal, and this is a direction in which further experiments may be made with a fair prospect of success.

The cupola in which the sponge was melted at Woolwich was only 13 feet high, and the blast furnace trial at Warora showed that the coal, or the coke made from it, might be worked in a furnace of nearly twice that height, if not in one still higher.

Where good coal or coke is to be had, it would be needless to divide the blast furnace process into two stages, making reduced spongy iron in one operation, and melting this in a cupola in a second, but as, from the softness of Warora coke, it is doubtful whether a blast furnace sufficiently high to be economical can be worked with it, this mode of treating the ore may prove to be the cheapest and best, if only by the methods of working suggested the metal obtained can be kept sufficiently free from sulphur.

The trials made by Mr. Ness to produce malleable iron from the Chánda minerals, by heating together mixtures of powdered ore and coal, were not encouraging, the yields being irregular and small, and the metal, in most instances, very red-short. It contained little sulphur, two samples of iron reduced thus in Dr. Siemens' rotating furnace, at Towcester, containing respectively, by Mr. Riley's analyses, 0·021 and 0·028 per cent. of sulphur, and a third, made in a Siemens' puddling furnace, at Holytown, near Glasgow, containing only 0·015 per cent. Its bad quality was thus due rather to the quantity of earthy matter, probably ash from the coal, that it contained than to sulphur, and it is possible that, by adding suitable proportions of lime and of manganese ore to the charge, as fluxes, this earthy matter may be removed, and good iron obtained.

It is not likely, however, that this mode of working will be able to compete with the reduction of the ore, in the first instance, to sponge, and the welding of this together and balling of it up, in a puddling furnace.

The output of a furnace working raw ore will be less, the waste of iron in the slag will be greater, and the metal will be mixed with much more earthy matter, and will be less easily obtained sound and free from red-shortness.

V.—*Conclusion.*

In conclusion, I am of opinion—

1. That iron and steel making in the Chánda district must be regarded as still wholly experimental, and that, if furnaces or other apparatus are put up, they should be all on a small scale.
2. That the iron ores of the district are of remarkable richness and purity, and that good limestone for smelting is to be obtained, but that the softness of the Warora coal, when charred, renders the successful working of a blast furnace with it very doubtful, and if a furnace can be worked, the low percentage of fixed carbon that the coal contains, together with the refractory character of the ores, will render a large consumption of coal needful per ton of pig iron made.
3. That if any coal can be found in the district that yields a harder coke, it may be worked in a blast furnace without difficulty, and that if a coal can be found that contains more fixed carbon, it will be more economical than Warora coal in the furnace, and less of it, in proportion to the pig iron made, will be required.

The relative hardness of the cokes of different coals may be compared by testing them, under similar conditions, in a revolving drum, like that used in the experiments described above. Cast-iron or leaden balls will be more suitable than a stone for crushing the coke.

4. That the only form of blast furnace that is at all likely to work well, with Warora coal or coke, will be a low furnace, about 40 feet high, with the shaft divided into compartments by vertical cross walls, on Mr. Ferrie's plan, so as to partly support the charge, by friction against the brickwork, and keep it from crushing together too heavily in the lower part of the furnace.
5. That even with a furnace 40 feet high, the blast should be very hot, heated to 1,400° or 1,500° Fahr. by fire-brick stoves, preferably by stoves on Mr. Cowper's plan.
6. That the question whether a blast furnace, 40 feet high, can be worked with Warora coal may be determined, very simply, by altering the experimental furnace at Warora, increasing its height to 40 feet, and reducing its diameter to 5 feet, and working it with the same blowing and blast warming arrangements as before; and trying whether, in such a furnace, pig iron can be produced with this coal.

If it can, there need be no hesitation in going to the expense of putting up a larger furnace and hot blast stoves.

7. That spongy iron, of good quality, may be made at Warora by the Blair process, and that there will be no difficulty in making the sponge into steel, by fusion in crucibles, but that this mode of working is expensive, particularly in melting a material of such low density as the metallic sponge, and that it is suited only for making small ingots of hard steel, while, as considerable skill is required to make the steel of regular hardness, suited to various purposes, this process, too, must be regarded as experimental at the first.
8. That the open hearth mode of working is the only plan fitted for producing steel cheaply, and on a large scale, from iron sponge, but that, as it was carried out by Mr. Blair, it required the use of so much pig iron, in addition to the sponge, as to be unfitted for adoption at Warora, unless pig iron of suitable quality can be made on the spot; and that Mr. Ireland's proposed modification of it will also be inapplicable, unless means can be found to

keep the metal produced by melting down spongy iron with Warora coke, in a cupola, nearly free from sulphur.

9. That the problem how to keep sulphur out of the metal thus obtained has an important bearing on the prospects of making steel cheaply, and in quantity, in the Chánda district, and that experiments to determine whether it can be solved are very desirable.

These may be made in England, and with English foundry coke, as, if metal nearly free from sulphur is obtained with such coke, equally good results may be reached with Warora coke, as this contains no exceptionally large proportion of sulphur, and the trial at Warora proved that it can be worked in a furnace at least 24 feet high. The experiments should consist of melting spongy iron from the Chánda ores, in a cupola, with manganese ore, and with the greatest possible proportion of lime, together and separately, and determining in each case the proportion of sulphur in the metal tapped out. Cold blast may be used, first, and if a sufficiently good result is not obtained with this, very hot blast, heated by Cowper's stoves, should be tried. Mr. Cowper may be able to arrange for the carrying out of the experiments with hot blast at one of the works where his stoves are in use.

10. That the sponge from the richer ores may possibly be balled up into lumps pure enough to be made into bars of merchant iron, but that this is a matter to be determined by trial.

Meantime, a small Blair reducing furnace, such as Mr. Ireland proposes, and a 6 or 12 pot crucible steel-melting furnace may be prudently put up at Warora, as there is no doubt that good spongy iron and excellent tool steel can be made from the materials of the district.

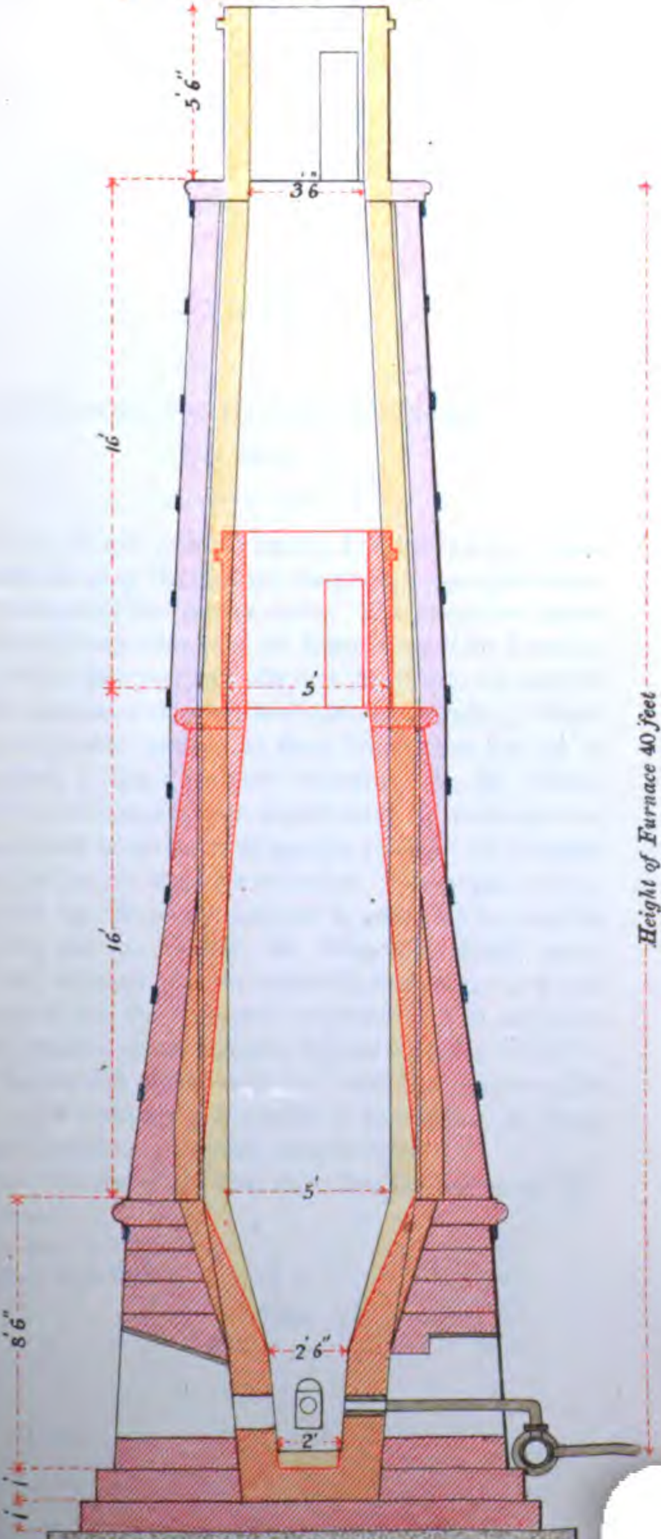
I have no practical knowledge of the Bicheroux steel-melting furnace which Mr. Ness recommends, and cannot give any opinion as to its working.

I have confined myself, in this report, to the consideration of some of the technical questions bearing on the prospects of iron and steel making in the Chánda district, and have not attempted to make any estimates of the costs of production.

CLYTHA PARK ROAD, NEWPORT, 16*th February*, 1879. W. H.

REPORT ON THE IRON AND COAL FROM THE CHÁNDA DISTRICT OF THE CENTRAL PROVINCES OF INDIA

Scale, 6 feet to an inch.



No. CCCXXVIII.

INTER-OCEANIC CANAL PROJECTS.

[*Vide* Plate.]

EDITOR'S NOTE.—In last quarterly number I published a paper about the Inter-Oceanic Canal by Mr. Menocal, imagining it was a plain statement of the advantages of the various routes. The discussions on the paper in the two following numbers of the Transactions of the American Society of Engineers show very decidedly that this view is not accepted generally by the members, no less than twelve gentlemen having "offered remarks" of considerable length. As these Transactions are not in general circulation, I reprint the first "discussion" by Mr. Walton W. Evans, as the most complete view of the through sea level advocates, and at all events it will be allowed to be amusing reading. Of the other members some are for one some for the other. The general opinion seems to be that Mr. Menocal's estimate is much too low for the Nicaraguan route, and one member, Mr. Edward P. North, states that none of the estimates give the total cost, he writes—"It is well known that in addition to the engineers' or absolute cost of any work, there are other expenses—some perfectly legitimate—which depend so largely on the honesty and discretion of the board of direction on the one hand, and on the confidence of the public in the scheme on the other, that it is almost impossible to correctly estimate them.

"An analysis of the cost of the Suez shows that the two items were in round numbers—

Absolute cost, ...	$48,000,000
Expenses of administration, ...	50,000,000
Total, ...	$98,000,000

"As in the present case there are rival projects in the field, and no route is now known that does not present complications, which though doubtless surmountable, will tend to alarm timid investors, and as the work is much further from the accumulated capital and low rate of interest of Europe, it may be assumed that even under Count de Lesseps experienced guidance, these administrative expenses will amount to at least 115 per cent. in place of the 104 per cent. of the Suez Canal.

"As a careful location has been made only on one route, and that is now generally admitted to require revision in the matter of curves, locks, &c., no estimate of the absolute cost can be advanced as more than a rough approximation, but the general impression seems to be that it will be in the neighbourhood of $120,000,000; if to this $138,000,000 (115 per cent.) be added for administrative expenses, we will have the cost at completion $258,000,000.

"It can hardly be expected that on the completion of this canal the routes of commerce will immediately change, and even if that were probable, the investors must wait for an increase born of the facilities afforded by the canal before they can hope to receive a satisfactory income from their expenditure.

"As even a small railroad enterprise, shortly after completion, passes through the various phases of floating debts and ingeniously-named mortgages—if happily it escapes the hands of receivers, this canal, if ever built, must probably see its immense capital nearly if not quite doubled before its dividends can equal 15½ millions or 6 per cent. on the cost at completion."

The point noticed above that the surveys and data for any of the estimates are most incomplete is insisted on by most of the other members.

Mr. Julius W. Adams takes an entirely different view from all, and advocates a canal through the Isthmus of Tehuantepec, *vide Plate*. His argument is that the canal should be first for America, and should be entirely in the hands of America—"no European co-partnership." "The desire to make the Gulf of Mexico a closed American sea is as natural to us as a similar policy to other powers in regard to the Black Sea, the Caspian, the Zuyder Zee, and others." "There is no more reason why foreign nations should be allowed to guarantee the neutrality of an American thoroughfare than that the United States should be a party to defend the British Channel, the Straits of Gibraltar or the Isthmus of Suez." "A canal terminating in the Gulf of Mexico would be easily protected in time of war, and by making, in case of need, the Gulf a closed sea, our merchant marine would be safe from all attack, and our relations with the Pacific could be sustained without any interruption." But while starting on this basis as the most important point, he gives tables of routes, results of which are somewhat shown in the Plate, to show that independently of this, the upper is the better route. He states there is ample material and excellent climate on the upper route, but says there are no surveys on which to base an estimate. Comparing however by length and lift with Mr. Menocal's estimate for the Nicaraguan at the same rates, he runs out a rough estimate of 58 million dollars, against the Nicaraguan 66 millions. He allows that the transit will be 67 hours against Mr. Menocal's 38½, and he concludes as follows:—

"Whatever may be the advantage in point of time of a transit at Panama over that at Nicaragua, as we are dealing with the latter entirely in this comparison, we have to state that the passage of the Tehuantepec Canal will require one day more than the canal at Nicaragua, or, at the outside, two days. As regards the objections to locks—whatever route be adopted, even the through cut, so called, if it can be built, will require a tide-lock, at least, on the Pacific. In admitting that mean tide on either side would be at the same time the rise on one side of 20 odd feet, and on the other of 1½ feet, would require a tide-lock for adjustment of current. The fact that the Red Sea level was *traditionally* some 30 feet above the Mediterranean, and results demonstrated in a canal of 90 miles in length, connecting the two, that the difference was really inappreciable, has no bearing whatever upon this question.

"The route which, as we have seen, while giving all proper facility to European commerce through American water-ways, still from its geographical position gives a proper preponderance to our domestic commerce, requires the use of lift-locks. Shall 24 or 48 hours additional time for its passage, and the bugbear of the danger of such transit, which differs but in degree, and not in kind, from the most favorable route which European interests can point out, deter American enterprise from carrying out what the interests of her growing domestic commerce calls for, and leave her to gather such crumbs as older nations have determined shall be her share?

"Public opinion is beginning to express itself, in a manner not to be mistaken, adverse to any foreign occupancy among the small States of Central America, where a question of the infringement of the rights of such occupants by the local government could so easily be made the pretext for the interference of a foreign power, ostensibly for the protection of the rights of its own citizens, but virtually to deprive this Government of the control of her own domestic trade. This feeling has been aroused by the late movements of a French company at Panama. But, indeed, either at Panama or at Nicaragua, if a ship canal should be built under circumstances of control nominally favorable to this country, and in accord with the spirit of the Monroe doctrine, as we construe it, yet its location, although endorsed by high officials, would, as we have seen, be so much more favorable to foreign than to American commerce that the legitimate growth of the latter would be completely crippled; and to prevent such a consummation we must go still further, and refuse countenance or support, in any way, to the construction of a ship canal located at any point south of the Peninsula of Yucatan; or, in other words, south of the Isthmus of Tehuantepec. And the importance of enlightening our people as to the national bearing of this question of the location of a ship canal cannot be over-estimated. It is no longer *who* shall build it, nor *how*, but *where* it shall be built, that interests us as American citizens."

Discussion by WALTON W. EVANS.

I beg to offer a few remarks in discussion of Mr. Menocal's paper on the much-vexed project of the Inter-Oceanic Canal. I wish to give, first, my reasons for venturing an opinion:

1st. I have served for seven years as an engineer in the construction of canals.

2nd. I have had an experience in the construction of public works of over forty-two years.

3rd. I have crossed the Isthmus many times—partly by foot, by mule, by canal, and by rail.

4th. I have been detained on the Isthmus for weeks—by rains, revolutions, and want of transportation—before the railway was built.

5th. I have witnessed the heavens open their flood-gates, and seen the terrible washings the railway was subjected to.

6th. I have lived in earthquake countries for eleven years, and have witnessed the convulsions of Nature on the Isthmus as well as in Peru and Chile.

7th. I have, for over thirty years, made a study of this most interesting problem of cutting a canal for the largest ships through the narrow strip that divides North from South America.

8th. And I have read with care most of the public documents published in reference to it, and am clearly of the opinion that the "San Blas" route for a sea-level canal is far preferable to the Nicaragua route, with locks, or any other route ever reported on.

I beg to present some axioms in reference to this great problem:

1st. A canal thirty miles long is preferable to one a hundred and eighty-one and one-quarter miles long.

2nd. A canal without locks is preferable to one with locks.

3rd. A canal that has good harbours at its *termini* is preferable to one with no harbour at either end.

4th. A canal built in a healthy region is preferable to one it an unhealthly region.

5th. A canal that can be navigated in ten hours is better than one requiring one hundred hours.

6th. A canal that will call for very small repairs is preferable to one requiring immense repairs.

7th. A canal that has a small "water-shed," but a sure supply of water, is preferable to a canal having a great "water-shed."

8th. A canal that is not on a line of drainage is preferable to one on a line of drainage.

9th. A canal that can pass a ship of any length is preferable to one that limits the length to far below that of many existing ships.

10th. A canal that is virtually a straight line is preferable to one with many curves, some of them very objectionable.

I have read with care Mr. Menocal's clever paper, and beg to take issue with him on some points. He starts off with the assertion that the matter is narrowed down to two routes—the Panama and the Nicaragua. I should have been better satisfied if he had said the San Blas and the Nicaragua, for I look on the Panama route for a sea-level canal as simply ridiculous. I intimated the same, but with less forcible words, to Count Ferdinand de Lesseps, in Paris. After many years of study of this matter, and after for a time believing in the Nicaragua route as the proper one, I came to the conclusion that the San Blas route had many features in its favor that placed it far in advance of all others. I refer to the foregoing axioms for those features. I beg to say a word in defence of Count Lesseps. I have an impression that he is thoroughly honest, and find that is the opinion of all my friends in Paris who know him well. I think he was, in the conducting of the Congress, influenced by men who hoped to grow rich through the use of his name. He will soon see the error he has made when he reaches the Isthmus, and is made acquainted with the terrible destruction of the late floods. He said to me in Paris: "There is one point in this matter we must observe: wherever the canal is built *it must be a sea level canal.*" In this I fully agree with him; and I will add one more important engineering feature: it must not be built on any line of drainage, or across any line of drainage. What we require—what the world requires—is a perfectly reliable canal, that cannot by any accident run itself dry; that is perfectly secure against the accidents that can occur and do occur to all canals depending on dams and locks as working features, no matter how well and costly they may be built; if we cannot give the trade of the world such a canal we had better give it none.

I would not propose to run the San Blas canal into the Rio Bayano, but turn that river off into the Bay of Panama by a cut made expressly for it; this could not be done for the Chagres River, except at an expense of many millions. It it proposed to build the Nicaragua Canal in the Valley of the San Juan, and in close contact with the river for many miles. I would suggest to the advocates of that route, and to the capitalists who I am told stand ready and eager to put their money in it, to first visit the Valley of the Lehigh, in Pennsylvania, and view the ruins of what was, within my recollection, a canal that received the praise and admiration of everybody; it was built by skilled engineers; the money furnished by the most careful and long-headed Quakers of Philadelphia; it had locks of thirty feet lift, the greatest ever put on a canal; the water-shed of the Lehigh is very insignificant; all the owners slept, no doubt, quietly in the possession of what they supposed to be a very safe investment; but a storm came—a flood was the result; this little lamb-like river became a great, fierce tiger, bent on destruction; a weak point was found in the upper dam, the tiger poked his nose in it, a little leak was started, and away went the whole structure; with it went every dam and lock on the whole river, and hardly left a wreck behind; no one ever had the courage to rebuild that canal. There are many among us that recollect the destruction of the Croton River Dam; placed at the initial point of the Croton Aqueduct, it was built under the plans and direction of that Nestor in American engineering, John B. Jervis; he was an old and skilled canal engineer. Who have we at the present day who is his superior? That dam was built on rock, where the best of materials and skilled workmen were to be had in profusion; but it went—carrying havoc in its course—and destroyed every bridge, dam, mill, factory, and building it could reach down to the Hudson River. I well remember this river above the dam, and its lamb-like character in summer, for I built a railway on its banks, and have many times crossed it on stepping-stones without wetting my boots. The European news of the past two days tells us of floods in Hungary, and that many dams have been carried away on branches of the Danube. I for one would rather trust to a tunnel than a dam. I have had a good deal to do with dams, and I feel towards them as Robert Stephenson once told me he felt toward railways, that he was afraid of them.

There are other things that I would be afraid of in the construction of a canal with elevated reaches on the side of a valley where such rains occur as are frequent in the San Juan region, I mean the melting and running of the embankments. Once on arriving at Panama on my way home I was told I could not cross the Isthmus, as there was a wash-out a few miles from Panama. I took a hand-car, went to see it, and found Col. Totten there making an embankment of sleepers. This same embankment had been washed out three times before, and every time it had been, when rebuilt, reinforced by a row of piles, close together, on the down-hill side. Col. Totten said to me, "You see this embankment could not go out down hill this time, so it has gone *up hill*." It had actually squashed out on the up-hill side, and had run very much as molasses would run; a horse or man going into it would soon have gone out of sight. To know the Isthmus and its rains, and what rains can do in the way of making running mud out of embankments, it is necessary to go there and see it, for no one can imagine it from any pen sketch. I have an impression that all the arguments that can be urged against the Panama route will hold good against the Nicaragua, while the Panama route, adapted to have locks, has the advantage over the Nicaragua in the matter of length and harbours at the termini.

Mr. Menocal's estimate of cost appears to be made as many other estimates of cost of public works have been before his time, by dealing in too small figures, and making omissions. His estimate for drains (I suppose this covers aqueducts over side rivers, culverts over streams, changes of channels, waste-weirs, sluices, &c., &c.) is magnificently deficient, and I see no items for protection walls, inside and outside, puddle walls, lining to prevent leaks, gravel facings, &c., &c. Also draw bridges over the canal, light-houses, machine-shops, and whole villages of buildings for residences, &c., store-houses, &c., &c. I suppose these are all in the twenty-five per cent. for contingencies. I have found in practice that after estimating every item I could think of, the twenty-five per cent. for contingencies came in as a most comfortable assistant at the end. Captain Young, who built the Utica Railway, used to say that the only safe way to make an estimate, was to take the largest quantities you could get from the profiles, carry them out with the largest prices you ever heard of, add twenty per cent., and then double the whole. When the first estimate of the Hudson River Railway was made, there were many arguments offered to show that it could be built for about "half of nothing," the engineer gave the size and number of every arch and culvert required on the whole 145 miles, for each division. I, having a love of statistics, counted them, and found there were about sixteen or eighteen in all. Now, this same engineer had just before built the Croton Aqueduct over forty miles of the same route, and close to it, and had forgotten that he had built over three hundred culverts, arches, and bridges, on that forty miles. The protection walls for this railway, amounting to over 400,000 cubic yards, were estimated to cost fifty cents per cubic yard, and it was forgotten that the protection walls of the Croton Aqueduct (now nearly all, inside of forty years, replaced by better walls) cost $1·75 per cubic yard. I mention these things to show how errors creep into engineers' estimates, even among the most conscientious—their zeal, their desire, their anxiety to see their project go down the throats of somebody, overrides their judgment and stores away in oblivion for a time all their hard-earned experience, making true at this day the old Roman motto, "*Men try to believe what they wish to be true.*"

The Nicaragua route calls for the construction of artificial harbours at each *terminus*. This is a most unfortunate feature of this route. Such things have to be approached with fear and trembling, and a pocket full of money, and after they are built and handed over as something to be proud of, they, or their parts, very often go on excursions up and down the coast, through the alluring enticements of the wind and the sea. Some have their usefulness nipped in the bud by a failure to find funds for their completion, as was the case with the Dover Harbour, in England. I had occasion to examine those works in 1853, and then came to the conclusion that although "John Bull's" purse was long and large and full, that he had better leave that work alone, and since then he has left it severely alone. The one long wall which I saw in 1853, I was again on in June of this year, and found it had neither grown higher, longer, nor more complete, and its partner had never been attempted. In March of this year I walked, or rather clambered, out for a short distance on the concrete breakwater for the harbour of Port Said, at the northern *terminus* of the Suez Canal, found that it was far from finished, and unless finished would in a few years be knocked to pieces and rendered useless. In November of 1878 I had a chance to examine the concrete works of the harbour at Algiers, built by the French, evidently at great cost. The waters of the Mediterranean had quietly or unquietly, as the case may be, just knocked a considerable part of it into a "cocked hat," and the Algerines were, in their faith, no doubt, praying to "Allah" to knock the "cocked hat" into "pi."

Artificial harbours are contrivances to be avoided, if possible: they are apt to give engineers sleepless nights, to deplete plethoric pockets, and vanish when called on by the winds and the waves.

I have some experience in sleepless nights produced by things of this kind, for I built out into the Pacific Ocean the first pier ever built on the whole coast of South America, that a big ship could haul alongside of. The "Brave south-west winds" as Maury called them, were my friends for thirty days out of thirty-one, then "Æolus" sent "Boreas" down to make things lively with his "big guns," and at the same time make an engineer's heart sink into his boots. During construction I often saw the northers rolling in the waters, which went over my pier from 20 to 30 feet high, and bid fair at times to carry the whole structure, with its 80,000 tons of stone, on to the beach.

Mr. Menocal estimates the locks between gates to be 400 feet long; a lock of this length will pass a vessel of only 360 feet. Thirty years ago vessels of 360 feet long were scarce articles; we have now lots of vessels of 450 feet, and vessels of over 500 feet are being built. Who can say what will be the length of vessels in another thirty years? The locks of the Erie Canal of 1825 could not pass boats of half the size that are now locked through.

The locks of the Delaware and Raritan Canal had not been in use thirty years before they had to be doubled in length. I came through the Suez Canal in March in a Peninsular and Oriental Royal Mail steamer from Hong Kong and Bombay, that was over 400 feet long; other steamers of that line are over 450 feet long. I saw a number of steamers in the canal, and judge that most, if not all of them, were over 400 feet long; it would be a sorry mistake to build a canal with locks that cost over $300,000 each, and find that they could not pass these giant craft, for they are the cream of the business a canal company would seek.

The Suez Canal is virtually a straight line. When I arrived at Lake Timsah we found a huge steamer stuck in the mud in the lake, and a crowd of Arabs unloading her; the canal ahead was blocked; I took a steam pilot-boat, went ahead to see the difficulty, and found that a passing steamer had run into and sunk one of their large dredging machines; this once clear, the next day our Leviathan attempted the passage to Port Said, but we had hardly run in the canal a mile before our vessel run her bows into the right bank, her stern slewed around and went into the left bank; there we stuck for two hours, and in two hours more our craft was laid along side for the night, that being her second day in the canal; this steamer entered the canal at 4 P. M., March 22nd, and arrived at Port Said at 10 A.M., on the 24th, taking 42 hours to run just 100 miles in a sea-level canal, virtually one straight line. The very next mail steamer of the P. & O. line that came through after I did, ran into the bank, her stern swung into the opposite bank, and broke off two of the blades of her propeller. Accidents like this, of running into the banks, being apparently common on straight lines, it would be well to examine carefully into the manner of working these long steamers around the sharp curves of the proposed Nicaragua Canal.

We in America know that the English locomotives have a very unmannerly habit of jumping the track at sharp curves, which habit we in America have almost entirely eradicated from their vicious propensity by rendering them subservient to the ameliorating influences of a "Bogie," a mechanical persuader which accomplishes the object in a most satisfactory manner; if this admirable invention could be applied to a ship, we might overcome the difficulty; as yet I see no manner of making the application, but the Yankee brain is prolific, and some genius may work out the conditions of this important problem. Old canal men and sailors accustomed to handling these huge vessels will look with a smile on the estimate of 38½ hours to pass through a canal 181¼ miles long, with many sharp curves and 22 locks; also the estimate of 20 minutes to a lock; to fill or empty a lock in 12 or 14 minutes would not be a difficulty, but that is only a small part of the time required to pass a lock; it must be recollected that a vessel has to be "slowed down" long before she reaches a lock, and in most cases come to a dead stop before she enters the lock, then to be hauled in slowly and with care, for if a large steamer, weighing with cargo 8,000 or 9,000 tons, enters or approaches a lock with any amount of headway on her, she will probably walk through the lock without asking permission, and in much less than 20 minutes. If any such trade as would certainly be offered to a sea-level canal were offered to a canal with locks, there would, most undoubtedly, be great detention at the locks, by one vessel finding another vessel in the lock, other vessels ahead of her, gates shut, lock empty, &c., &c. If any one thinks these large vessels can be started and stopped, and turned like children's toys, let him go down to the piers in New York and see one of these large steamers arrive and get berthed. I arrived in July in the Britannic, and we were full one hour from the time we touched the dock until the ship was hauled into her berth. Taking my trip on the Suez Canal as a base for calculation, I would make the time of passing the Nicaragua Canal as follows:—the speed was a mile in 25·2 minutes; 181·25 miles at 25·2 minutes per mile, 76 hours; 22 locks at 1½ hours a lock, 33 hours; total 109 hours; or, say 4½ days, and this may be put in opposition to one single day of ten hours in passing the clear, straight, unobstructed 30 miles of the San Blas route.

Mr. Menocal estimates the cost of the Nicaragua Canal at 66 millions dollars. Men with experience and analytical brains have criticised this estimate and found it deficient. I agree with them, and further believe that the dimensions estimated are not such as a world's Canal calls for and should have, particularly in available width and depth, and more particularly when carelessly handled ships are to be encountered. In going out of Marseilles harbour just one year ago in a straight channel of double the width of the canal proposed, our French captain had all his yards squared; he met an incoming brig, his vessel did not touch the brig by fifteen feet, but his main-yard struck the foremast of the brig and snapped in the middle, broke the fore-top mast of the brig, and down it came with all its spars close to the spot where I was standing with some ladies.

In pushing and preaching the merits of the Nicaragua route, there appears to be a fixed intention to ignore the San Blas route entirely, and "pooh-pooh" it out of sight; they may knock it down, but it will come up again; they may throw cold water on it, but it will come out of the fire brighter than ever; they may build the Nicaragua Canal, but the San Blas will be built too, and then it will require no very wise man to tell which will be the one used. In the papers and estimates made out to compare the different routes, I see nothing said of comparative cost of repairs and maintenance; leaving the Panama route out as an absurdity, the lengths of the San Blas and the Nicaragua are as 1 to 6, but when it is considered that one is a sea-level canal, with good harbours and without locks, cut for a large part of its length through solid rock, the southern half in an open "savanna" country, the whole easily made safe from the ravages of floods and drains; while the other route is on and parallel to a tremendous drain, where floods occur that may and probably would sweep the whole works to destruction in a few hours; where earthquakes may and probably would twist the locks so that the gates could be neither shut or opened; where side streams, with their floods, must cross the canal to get into the main drain; where the time of transit compared to the San Blas is as 5 to 1; where there are no good harbours at either *terminus*, and where one *terminus* is a notoriously unhealthy place. I think any careful and critical mind would put the ratio of conservation of the two routes not as 1 to 6, but as 1 to 20 or 30, or more.

A five-inch rain falling in twelve hours is a thing not unknown in the Nicaragua lake region; as the water-shed of the San Juan River is 12,500 square miles, a five-inch rain is represented by over 4,000 millions of tons of water, a greater part of which has to find its way to the sea by the San Juan river, and not take a great length of time either; it was undoubtedly after one of these great rainfalls that the San Juan River, rising above its banks, overflowed, and cut the Colorado River into the territory of Costa Rica. Those who are curious in the matter, might calculate the foot-pounds of energy or force developed by 4,000 millions of tons of water falling 107 feet, and its power for doing mischief.

Apparently the only objection to the San Blas route is its cost growing out of a long tunnel, and the inability to say what kind of material would be found in the tunnel. Let us examine this great bugbear, the tunnel, and compare it with other works.

The "Desaguadero" in Mexico, cut by the Spaniards, as a matter of precaution against floods, two hundred years ago, required about three times as many cubic yards of rock to be removed as would be required to cut a ship-tunnel 8 miles long, 180 feet high, and 80 feet wide. Now, if the Spaniards could do that two hundred years ago, should we, who have steam drills and wonderful explosive compounds, shrink in fright from a work of only one-third the size?

The St. Gothard Railway, now nearly completed in Switzerland, to connect the northern railway system of Europe with that of the South, is a work that involves immense difficulties. It has on its line forty-six tunnels, one of them at the summit being over nine and one-fourth miles long; one of them the engineer pointed out to me as being cut to secure the railway line from being buried by avalanches. Seven of these tunnels in complete circles of 1,000 metres diameter, are cut merely to get distance, and keep the gradient down to their fixed standard of 1 in 40 (132 feet per mile), and this tremendous work is being built for the very limited business of a railway. With this example staring us in the face, are we Americans, who boast ourselves of doing things with a bigger "auger" than our neighbours use, to turn tail and run away from a tunnel that would, if built, command the trade of the world, give us a grip on the trade of the whole Orient, allow us to manufacture all our own cotton and find a market for it in China, connect our Pacific possessions by a less expensive route than any railway can supply, consolidate our Union in stronger bonds, and lead in time to our becoming the most central and most powerful people in the world.

It has been objected to this tunnel, and reiterated by Mr. Menocal, that the rock found in it may be too soft, or of a character not fitted to support its sides and roof. This is all "moonshine." We know from mines and cuttings over all that country, and from surface rock that crops out everywhere, just what we may expect; there is but one material existing that we may be afraid of, and even that was successfully overcome in the Box-tunnel of the Great Western Railway of England—I mean quicksand, and that we know we will not find under the rocks of the Isthmus. Mr. Menocal thinks we have not the data by which we can calculate the cost of the San Blas Canal as fixed and clear as they have for the Nicaragua Canal. If they have not these data it is their fault; they should have got them; but I contend that we have all the data required, and more reliable than any data ever can be, on a line parallel to and close to a line of drainage, that Domine Sampson might call with truth, "prodigious:" we have the length of the whole route: we know what is tunnel and what open cutting; we know to a certainty that we can turn off all the streams and the one river, the Chepo or Bayano, and render them harmless to do evil. We know that we have good harbours on this route; we know that we have rock to contend with in fixed quantities, and by estimating it as granite, we know that the estimated cost cannot be far wrong. It has been intimated that earthquakes might make a tunnel unsafe and dangerous; in answer, I would say that we have sixty-two tunnels on the line of the Oroya Railway in Peru, that many of them are completed and have been run through for years, and to this day I have never heard of any injury done to a tunnel on that line from earthquakes, which are much more frequent there than on the San Blas route.

We need not be afraid of striking a great vein of gold or silver, for in a case of that kind, unless the tunnelers become demoralized, such a vein might be coaxed into paying all or a part of the expense of the tunnel. This is not a speculation, unprecedented in facts, for my old friend, Genl. O'Brien, when forced by San Martin, the Liberator, to accept the Salcedo mine, in Peru (the richest mine at that time that had ever been worked), for his services in the wars of independence in Buenos Ayres, Chile, and Peru, struck a rich vein of silver in cutting an adit level from Lake Titicaca that paid all the expenses of cutting the tunnel for a long time. If some of the Bonanza kings of California could be induced to suspect another Comstock Lode on the line of the San Blas tunnel, they would cut the tunnel for the fun of the thing, and thank you for the chance. But if we throw out the silver speculation and return to the "hard-pan" of a hard-hearted contractor's prices we may have the following estimate to stare in the face:—

14 millions of cubic yards of rock in the tunnel above the sea level (the tunnel being 8 miles long, 150 feet high above the sea, and 80 feet wide), at say, $3 per cubic yard, ...	$42,000,000
4 millions of cubic yards of work in tunnel below the level of the sea (this part being 80 feet wide and 30 feet deep), at say, $8 per cubic yard, ...	32,000,000
22 miles of open (earth and rock cutting) canal at the same price Mr. Menocal estimates his line from Del Medio to Brito, where it is all rock, at, say, one million per mile, ...	22,000,000
Diversion of the Rio Bayano, say six times as much as Mr. Menocal estimates for the diversion of the San Carlos, $283,578 × 6, ...	1,700,000
2,400 acres of grubbing and clearing, at $100 an acre, the same as Mr. Menocal estimates an acre at, this gives a width of 875 feet for 22 miles, say, ...	240,000
Diversion of other streams, all small ones, say, ...	1,000,000
Light-houses, piers, store-houses, buildings of all kinds, say, ...	1,000,000
Total, ..	$109,940,000
Say, ...	110,000,000
Add for contingencies 25 per cent., ..	27,500,000
Grand Total, ..	$137,500,000

The above estimate is considerably above the estimate of Mr. Menocal for the Nicaragua route, but I will here venture to predict that it is very much nearer the truth of what the Nicaragua Canal will cost, if ever built, than Mr. Menocal's estimate. We may as well stare the truth in the face now as at any other time; it is the most honest way.

The people of the United States have had too much to do at home to look with much enthusiasm on works in distant countries or study with care the vast interests wrapped up in foreign trade; but the day is fast coming when they will be forced to know and value this matter, and then they will cut a canal through the Ishmus on the shortest route that can be found, no matter if there is a Nicaragua Canal or not. I am glad to find that all of the old canal engineers that have ever visited the Isthmus, and made a study of this problem, join me in the opinion that the San Blas route is the best for a sea-level canal, and the proper one to construct. And Mr. Kelley, who has spent his life and a fortune in surveys and study of this matter, and who has as clear an understanding of the whole subject as any man living, also most enthusiastically gives his adherence and support to that route as the only one that can satisfy the coming demands of trade, which is doubling up on us much faster than any one but those who study statistics could imagine.

As I feel convinced that the indirect benefit to the nation to be reaped from this canal is far greater than any direct benefit to any company, I would propose that the canal be cut, not on the line that is found to be the cheapest in first cost, but on the line that can be worked the easiest and quickest, and in the most reliable manner as regards line, level, repairs, and freedom from accident, even if it cost double the amount of the cheap and unreliable line. And in view of this end, I would, if I were the Government, offer to any company that would undertake this great enterprise, to *give* them one-half of the entire cost, and let them enjoy the rights, immunities, and profits of the whole thing, free of interest, for one hundred years; but reserving to the Government the right to take the whole at the end of one hundred years by paying one-half the original cost. It may not be out of place in this discussion to bring to the notice of the people of this day the prophetic writings of some who have preceded our time. Gouverneur Morris, the statesman, in a long letter, written in January 1801, to John Parish, in Europe, says:

"As yet, my friend, we only crawl along the outer shell of our country. The interior excels the part we inhabit in soil, in climate, in everything. The proudest empire in Europe is but a bauble compared with what America will be, must be, in the course of two centuries, perhaps in one."

Robert Stephenson, the engineer, in writing to his brother-in-law (in London), when he was here in 1853, after speaking in the most enthusiastic terms of the progress and development of this country, says:

"Considering these circumstances, and looking at the boundless rich territories which are being opened and extended daily, I confess I am entirely at a loss to figure to myself the part which the United States are destined to play in the world's theatre; their influence must daily increase, and when her inhabitants reach the coast of the Pacific their power must become predominant as a commercial nation." * * * "Coal which has hitherto given England her commercial superiority, is possessed by the States in almost incredible quantities; it has as yet scarcely been touched, because other sources of profit have presented themselves; but the day must arrive when, like England, the Americans will become a powerful manufacturing nation. If this be anything like the truth, how strangely must the relations between the civilized nations of the earth be changed—and then arises the question, so full of interest to an Englishman: Will England still maintain a good position in the struggle of countries, or will she, like other empires that have dropped into the past, begin to decline, and in her infirmity, like an aged parent, be obliged to look to her trans-Atlantic children for aid and support?"

We are fast arriving at the point predicted by Mr. Stephenson. We must have outlets for our products. In what direction can we turn for a market for our manufactured goods but to the shores washed by the Pacific and the islands of that great ocean? China and Japan, Australia and New Zealand, invite us to a close intimacy. The Spanish republics of the South American West coast offer us many tempting chances for trade enjoyed at present almost solely by England. The Orient and Occident of our own country wish to shake hands over a cheaper route of transport than any railway can supply. Let us mingle the waters of the Atlantic with those of the Pacific on the best, shortest, and most reliable route that Nature has furnished, or let us leave it entirely undone, for others of greater courage to accomplish.

I find in some of the discussions on this important problem that the San Blas route is called impracticable, but in no case is an attempt made to demonstrate the impracticability. Surely it cannot be because it is so short, so straight, so free from floods, locks, dams, and aqueducts, or can it be that it is rejected on account of its having good harbours, and in a healthy region, free from swamps and lagoons. What can the claim of impracticability spring out of that blinds the Nicaragua promoters to the many points of merit of the San Blas route unsurpassed and unsurpassable by any other route; there is but one point on this route that the objectors can fix their harpoons into, with any shadow of a chance of bringing it home to the minds of men as a dead fish. It is the tunnel; that is the bugbear, the stumbling block, that narrow minds and unprofessional minds cannot climb over, creep under, or swallow whole. I am inclined to think that the tunnel is one of the best features of the whole route; it will cost, no doubt, a rousing big sum, but the amount will be a mere bagatelle to its value and importance, and when built it will be the surest and safest portion of the whole route; it will be through solid rock, and remain for ever intact, requiring little or no repairs. The heading, a very insignificant part of the whole, would cost as much per cubic yard as any railway tunnel, but the balance down to the sea-water level could, in that region, be done cheaper and quicker than an open cut of the same dimensions, where the average haul was the same, for the reasons that the men can work continuously without being driven off by the great rains that are so common on the Isthmus, and they can work, as in all tunnels, night and day. This tunnel can be cut cheaper per cubic yard than any railway tunnel could be in the same region, and for the reasons that the great width of the tunnel allows the men abundance of room to work in, and use all classes of labor-saving machinery; the force of the explosive compounds can be utilized to a greater extent, as there is more room for expansion. Any contractor can afford, and will afford, to take such an immense work at much less per cubic yard than he would think of asking for a small tunnel, such as are built for railways, for he can afford to procure and use the most perfect, extensive and efficient machinery ever used on any tunnel ever cut. I was shown at the St. Gothard Tunnel steam drills that by slow motion and high pressures would walk into granite as a knife would into cheese; there was nothing used on the Mount Cenis Tunnel to approach them in efficiency. I was shown air compressors that kept their great reservoirs night and day under pressures of 110 pounds to the square inch, and without difficulty; it was with difficulty and uncertainty that the air compressors of the Mount Cenis Tunnel could keep the pressure up to 60 pounds to the square inch. We are clearly a progressive race, and it would be a wise brain that could predict with certainty what advance may be made by some live Yankee in tunneling machinery when we come to cut a ship tunnel. I have copies of the entire maps and profiles of the St. Gothard Railway, and I have no hesitation in saying that they show the most complete and perfect surveys yet made for any public work ever attempted by man. There were 400 engineers and their assistants employed on these surveys, many of them highly educated and experienced men; their estimate of the cost of this great work, 109 miles long, was 187,000,000 of francs; that was the sum placed before the public at the time the International treaty (of Germany, Italy and Switzerland) was signed, and a company formed to build the works, but they were only started when it was discovered, that, as usual, the works had been under-estimated, and the cost was going to be swelled to 289,000,000 of francs, showing an error in the first estimate of 102,000,000 of francs. Where was this tremendous error made—in the great tunnel? No, for the estimate of that was 70,000,000 of francs. Monsieur Favre took the contract to build it at 50,000,000 francs, and if he had lived would have completed it in the coming year, without asking favors or assistance. There is an inference to be drawn from this statement of amounts, regarding estimates and costs of work in tunnels, and general work, which the intelligent reader will quickly see. Mr. Menocal estimates his great canal, 181½ miles long, at $66,000,000; the St. Gothard Railway is to cost, for 109 miles, about $58,000,000; now, if the canal costs only as much per mile as this railway, it will cost about $97,000,000. The railway costs about $532,000 a mile, while Mr. Menocal estimates this great canal, with artificial harbours, great locks, but not large enough for great ships, great excavations of rock under water, great aqueducts and great dams, all liable to be swept out by the first great flood, and great embankments (sustaining a hydraulic head of 26 to 30 feet) perched upon side hills, all of which may be washed out through the never ending labors of rats and roots in boring holes, all complete and ready to accommodate the trade of the world, at $346,000 a mile.

It may be claimed that the rock excavation under sea-water level is the impracticable point. If so, are not the excavations under water on the Nicaragua route equally or more impracticable. Let us stare some of the facts of this matter in the face. Nearly all of the excavation of rock under sea level on the San Blas route will be in still water, not affected by currents or winds or tide, while the same class of excavations on the Nicaragua route, in the beds of the San Juan and Rio del Medio, and in the bed of the lake, will be severely affected by currents in the river and waves and winds in the lake. To excavate rock in a swift current, such as is to be seen in the San Juan, is a species of fun engineers do not much covet. General Newton preferred to burrow under rather than attack the current at Hell Gate. Then, as to the work to be done out in the lake, I have an impression that this feature has been very much under-estimated. Suppose we subject this to a few figures, from known data, at one point. It is to be regretted that there is no good hydrographic survey of this lake, so we must be content with such data as we can pick up. The history of this lake and river show that, some years ago, a certain Captain Sheppard took his schooner from the gulf up into the lake during a flood. He did this with great labor, by taking off his false keel and taking out his cargo, reducing the draft to about three feet. Once in the lake, he put on the keel, and, with the vessel loaded—drawing seven feet—he could not, in the dry season, get within two miles of San Carlos, at the upper end of the San Juan River. Now, taking this little piece of history to calculate by, and knowing the material to be rock, I make it that a canal only 100 feet wide (I call it 100 feet wide, not because that is enough, by three or four times, for the passage of a ship subject to the buffetings of winds and waves in a great lake and the canal out of sight, but because 100 feet is sufficient for the demonstration I wish to make), cut from the mouth of the river out into the lake, so as to have 28 feet of water all the way to deep water, will call for the excavation of about 1,100,000 cubic yards, which, at $8 a yard, will come to $8,800,000; but, for the sake of being generous and accommodating, suppose we call it the half of the above sum, and then it is six times as much as Mr. Menocal estimates as the cost of all the work to be done in the lake division, including mud and gravel, which, it is admitted, has to be dredged, and also the rock under water at the western end. Heaven only knows how much is required to be cut for a channel to get into the mouth of the Rio del Medio.

Let us return for a moment to the San Blas route, and take a fair, square look at the rock to be excavated there below the sea level. In the tunnel, where the great mass will be found, it may be dry, and it may not. Take it on the side of the "may not," and allow it to be as wet as ever was seen, is it supposable that any engineer in his senses, with but a smattering knowledge of hydrostatics, would attack it under water, when he can so easily build bulkheads, pump out the water, and work out the rock just as he did above the level of the sea. With this system of working kept fairly in view, I have a fancy that any intelligent man can see that this rock in the tunnel will come out more quickly and cheaply than will the rock in the bed of the lake, when the winds and the waves will be playing "hob" with the drilling machinery, and at times driving the men from their work. But suppose the work finished—who can estimate the distress of mind of a captain when he finds his ship in a great lake with a wave-swell of 8 to 10 feet and only 2 feet of water under his keel; and that, too, only in a canal out of sight.

In my estimate of cost I dealt in big figures, and estimated for a depth of 30 feet of water. To bring this to the 26 feet of Mr. Menocal's section, there should be deducted over $4,000,000. Then again the tunnel, on more accurate surveys being made, may be reduced to six miles instead of eight. This would reduce my estimate again by $15,000,000, and then the 25 per cent. for contingencies would come down some $5,000,000, making in all some $24,000,000 of reductions. But I prefer to let it stand as I had it, at $137,500,000, and time will show who comes nearest to the truth, for it is in my eyes a sure thing that a great world's canal will some day be cut on the San Blas route.

As the transit of any of these canals will have to be suspended during the night, and as the San Blas route is so short that it can be navigated from end to end in ten hours, or less, and as one passing place (at south end of tunnel) only is required, the whole of the rest of the canal can be made, and should be made, much narrower than would be allowable and required on the Nicaragua route, where passing places must be frequent and provided between all the locks.

As sailing vessels are destined to form a great feature in the traffic of this Isthmus Canal—a feature that the Suez Canal is entirely deprived of—I beg to refute the claim made by the Nicaragua projectors, that the Bay of Panama is difficult to get in or out of on account of calms. I have been at Panama for weeks—I have been a guest on board of a United States war vessel for two weeks in that bay—and I never saw a day when a vessel was detained there, or prevented from coming in by either calms or storms.

New Yorkers would feel very indignant if told that their port should be shunned on account of its being difficult to get in or out of, and yet, I suppose, they all know that sailing vessels have often been for days outside, afraid to come in, and for days, in the lower bay, afraid to go out, during times of storm and fog—two hygrometric and meteorological features never met with in Panama Bay. Let us place the "calm" claim alongside of the "impracticable" claim, and send them both to the safe keeping of croakers. Intelligent men of this age are not going to take much stock in those two articles of Nicaraguan faith.

It getting from our shores to China and Japan, the great objective points, we as a growing commercial nation should look with much respect and admiration on the pacific character of the Pacific Ocean. The Spaniards of old used to say that all a "skipper" had to do on leaving Panama for the Phillippine Islands was to set his course, tie his rudder fast, go to sleep, and not wake up until he reached the end of his voyage. Ships going from Panama to China can take a trade wind going and a trade wind returning. When the canal is cut, and we have a new highway to the East, this feature will play an important part in assisting us to the largest share of the trade and traffic of the Orientals—a trade which for centuries heaped wealth into the coffers of the Greeks the Jews, and the Armenians of the Mediterranean—a trade that England seized and grew her wealth and power out of, when Vasco de Gama showed her a new way to the East by the Cape of Good Hope, four hundred years ago—a trade that is destined to fall into our hands and give us wealth and power such as no nation ever held, as soon as we can muster courage enough to cut an Isthmus Canal on the shortest route that can be found, and throw it open for all the world to enjoy as best they may.

It may not be inopportune to mention in connection with this discussion that a late commanding officer of the United States Navy, now living in Washington—a gentleman well acquainted with Nicaragua, Panama, and the Pacific Ocean—once said to me: "I should be very loath to allow any ship I commanded to be run in a canal and locked up a hundred feet above the ocean. I should be afraid of never getting down again."

In connection with the risks run by placing a big body of water on the side-hill slopes of a river valley (in a region of great rains) in a prism made of cuts and embankments, crossing spurs of hills and ravines, and also to show the fallibilty of man's estimates, I beg to mention a little incident that occurred on the line of the Oroya Railway in Peru, in the Valley of the Rimac. The final location had been made, and for some time the construction of this railway had been going on in a region almost rainless. At a point in the valley where the line crossed the mouth of a ravine we had left an opening to be filled by a bridge of 100 feet span. At the head of this ravine some poor *peons* had been cultivating the soil on the top and side of the mountain by bringing the water of melted snow from other and higher mountains for irrigating the land, as water in many parts of Peru is valued like gold. The peons, with great labor, puddled and protected the edges of their "chacras" so as to prevent loss by waste. The water sunk into the soil, and permeated down deep through stratas of alluvium, gravel, clay, and loose rocks. This was close to and on the side hills leading down to the Valley of the Rimac. This gradual permeation of rock and gravel, clay and sand, with water had, no doubt, been going on for a long time. The water was trying to find its lowest level. The rocks and the earth were only waiting to be released from the bonds of cohesion that had held them on the mountain side for ages to show what attraction of gravitation could do. Day by day this insinuating element, water, was doing its work, in the dark and in the night. Ceaseless, unopposed, all powerful, it was cutting and severing the bonds of cohesion. The people in the valley in front of the ravine rested in quiet content. The peons of the mountain imagined no evil genius underlying their crops, but in a moment when no one suspected danger the whole mountain side started for a race to the valley. Five millions of cubic metres (about ten millions of tons) of rock and earth, gravel, mud, and water came rushing into the valley, crossed its whole width of 1,400 feet, surged up against the opposite side, rolled over and crushed out of sight all the houses in its annihilating course, and filled the valley with a dam 1,600 feet wide on the bottom and 108 feet deep. The average vertical fall of this vast body of earth was about 1,500 feet, and the horizontal movement over 5,000 feet. Surely water has power, and we are entitled to place it with its sister element, fire, as good servants but dreadful masters. Gouverneur Morris, the projector of the Erie Canal, proposed that it should be built without locks, and on a line that would give it a uniform descent per mile from Lake Erie to the Hudson River. What a magnificent idea. It was too magnificent for the time. A line of this kind would carry the canal to the south of Cayuga and Seneca Lakes. With fifteen millions of tons of surplus grain in the far West seeking a market on the Atlantic seaboard, it would soon make New York the imperial city of the world, if it could find its way by water lines, without one check or hindrance, from the great grain fields to the great city.

A canal built as Morris proposed would not have a greater descent per mile than is now existing in the Ganges Canal in India, which has a fall of fifteen inches to the mile, and is navigated in either direction with facility and certainty. I mention this canal and its gradient to show that even a guard-lock is not a necessity at the south end of the San Blas route to provide for the current that would be created in the canal at extremes of high and low tide of the Pacific, but a guard-lock there would be a convenience and an economy.

Since the above was set up, another number of the Transactions has come to hand, containing an account of the special meeting to welcome M. Ferdinand de Lesseps. M. Lesseps, it will be observed, states that he went out to examine the route selected at the Paris Conference, *i. e.*, the Panama, but he is equally strong in his condemnation of either lift locks as on the Nicaraguan or Tehuantepec routes, or tunnels as on the San Blas route. I think, however, I shall not err in printing the Proceedings *in extenso*, and it therefore follows here. I may remark also that M. Lesseps' estimate is 120 million dollars, but little under the figure predicted by Mr. Evans.

Introduction by O. Chanute.

Vice-President O. Chanute was in the chair, and after calling the meeting to order, said:

This is a special adjourned meeting of the American Society of Civil Engineers, held for the purpose of welcoming to the United States the distinguished Engineers who have just arrived from Central America, and of hearing what they wish to say concerning the American Inter-Oceanic Canal. We shall first be addressed by M. de Lesseps. As, much to his regret, he does not speak English, his communication will be made in French, and, at his request, a synopsis of each portion of it will be made in English by Mr. N. Appleton. M. de Lesseps will also answer any questions which may be asked. After he has terminated, we shall have an account of the works proposed, by Mr. J. Dirks, Chief Engineer of the canal from Amsterdam to the sea.

The American Society of Civil Engineers has heretofore endeavoured to contribute its share toward the understanding of the subject of the Inter-Oceanic Canal, by gathering information concerning the various routes, the plans proposed for the canal, their probable cost, and the commercial bearings of the project.

This it has done, not with a view to revising the plans of what is, after all, a private enterprise, nor to pass judgment upon them, for the Society commits itself, as a body, to no views, and neither for nor against any project, but rather to collect the data required, that its individual members might form an intelligent opinion concerning the merits and probable results of an important undertaking, in which the American public is to be invited to take a share.

Beginning in November last, with the reading of a paper upon "Inter-Oceanic Canal Projects," by Mr. Menocal, member of the Society, and one of the delegates to the Paris Congress, the discussion has been participated in by many prominent members of the Society, as well as by several gentlemen who promote particular routes, and we have been fully informed concerning the San Blas, the Nicaragua, and the Tehuantepec routes.

But little has yet been said in those discussions concerning the Panama route; it being generally felt, that pending the proposed revision of the location and of the plans for the canal, by the very able engineers who had the matter in charge, it was desirable, before any opinions were expressed, to await the announcement of the results.

We are now able to learn these results, as well as the facts and plans upon which they are based, in the most direct, certain, and satisfactory manner; for we have among us to-night, as a guest, the chief manager and promoter of the enterprise; a gentleman of world-wide fame, as the builder of the Suez Canal, who, having already accomplished labors which to other men would be the work of a lifetime, having connected in the face of the most strenuous difficulties, two great seas across the trackless sand of the desert, now proposes to perform the still greater feat of cleaving the American Isthmus asunder, to connect the two great oceans of the world. Gentlemen, I have the honor to introduce to you M. Ferdinand de Lesseps.

Discussion by M. Ferdinand de Lesseps.

Mr. President and Members of the American Society of Civil Engineers, Ladies and Gentlemen: I am very happy to be here this evening, not only because it gives me an opportunity to set forth my views on the great project which I have so much at heart, and which I think when completed will be so great a blessing to mankind, but also at finding myself immediately upon my arrival in America, the much honored guest of this Society of Civil Engineers, before which, above all others, I consider it proper that I should first address myself. I am not an engineer by education, having been for so many years in the profession of a diplomatist, yet I am happy to be received as an engineer, and I am happy on that account as well as for the personal honors which have been paid me and the many opportunities afforded me for seeing in the short time I have already spent on shore what were to me most interesting and instructive illustrations of American engineering, skill and science.

I desire to begin at the beginning. In 1870, soon after the completion of the Suez Canal, and after that work had begun to be put into regular use, I began to think seriously upon the question of an inter-oceanic canal across the narrow land separating the two oceans in the Western Hemisphere. The first difficulty was the supposed difference in the levels of the two seas. An impression that there was such a difference had gone out and in many quarters was seriously believed, though for what reason I could not find out. Upon a careful examination it was discovered that this difference of sea-level was a myth, and that the only basis of the myth was the ebb and flow of the tide, which differed on the two sides of the Isthmus, but which would make no difficulty in the construction of a sea-level canal—for that from the first was the sort of a canal on which I had set my heart, and which I will build or abandon the project. I will not take up the various steps through which we passed in the consideration of this problem, for I can assure you that there were much study and many investigations during the years intervening between my first determination on the subject and the present time.

I determined not to occupy myself with political opinions, but from the moment I began the enterprise to devote myself to the practical part of the undertaking. I looked at the subject from a commercial view.

I am convinced and persuaded that the enterprise will be not only for the great advantage of commerce, affording an easy route to the Asian continent or India or Japan, but will produce results which will develop the shipping interests of the United States to the place they occupied twenty-five years ago.

I had the honor of the acquaintance of Senator Sumner when he visited France, and he gave me many valuable figures on the state of

American shipping at that time. He stated that the tonnage of American commerce at that time was about 5,500,000 tons. England at the same period had about 5,000,000 tons. All the commerce of the earth could have been divided into three sections, America owning one, England another, and all other nations together having an amount about equal to that possessed by each of these. Since that time America has fallen away as regards maritime commerce, and especially since the opening of the Suez Canal. Its commerce is very low, much more so than it should be for a people so great and powerful as the Americans. But I reflected that this was not to remain so; it cannot remain so with the Panama Canal open to encourage American shipping, as it certainly will do.

The Suez Canal has had the effect of changing the commerce of the whole world, and improved its shipping to an extent altogether unanticipated. It has caused the building of large steam vessels, which have supplanted the sailing ships. You will see that a similar metamorphosis will follow the opening of a Panama Canal. American shipping has fallen off since the war, and the mercantile marine, I am informed, is now in a deplorable condition. The opening of such a canal would give a fresh impetus to the building of American shipping and assist you in regaining the position that you have lost. To-day I say to the American people, prepare yourselves in six or seven years to see your commerce extended from the North Pole to the South. When you shall have comprehended the importance of the canal, you will see that your commerce will be benefited according to your large population, and that no other country will have pre-eminence over you when the canal is opened. I work not for selfish motives, but for the interests of humanity. Should you not, therefore, concur in the project as other countries have done ?

I will compare the Suez Canal with that proposed at Panama, and show, as I hope, that the one across the Isthmus would be an easier matter than that joining the Red Sea and the Mediterranean. In the first place, there was no precedent for the Suez Canal in modern times. The ground had been a battlefield of nations since the commencement of historic times. In the time of the Pharaohs, there were fresh water canals in Egypt, in the construction of which the natural watercourses were often utilized.

The first canal proposed for crossing the Isthmus of Suez was in the time of Phillip II. He at first acquiesced in the idea, but being a very jealous monarch, and afraid that other nations might profit by the canal, he afterwards insisted that the project should be abandoned. An edict was issued declaring all men impious who should propose such a canal. Even if they spoke about it they were to be put to death. This was his order, and as they knew he had the power to carry it out, the subject of the canal was quickly dropped. I hope the example of Philip II. will not be followed in America. It would be very inconvenient for some of us to have such an edict in force.

Since the time of Columbus there have not been wanting those who thought that the American Isthmus could be traversed. It was first thought feasible by using the natural ports, lakes and rivers. The regular study of the question of the inter-oceanic canal began in 1875. There was then at Paris a universal geographical congress, and there I talked with Professor Nourse, from your Government offices in Washington, and I discovered how much interest was felt in the canal in America. I was charged to preside over the inter-oceanic section, and I obtained from Washington all the plans of proposed routes. Of all countries the most concerned was America. Some said that America did not want the canal, but I replied, "You deceive yourselves. America wants to develop commerce in the entire world." To prove that America wanted the canal, perhaps I exaggerated a little, but I said that she had spent already about $1,000,000 in exploration and in the attempts to find out how to start right in this great work. I said at the Conference that America having built a line of railroad across the Isthmus, it was a good argument in favor of crossing it at that point. The American engineers chose this route thirty years ago, and built their railroad there.

A new congress was proposed, to which that special question of the canal was to be referred. I wrote a number of letters to leading engineers in Europe and America, inviting them to come to Paris to discuss the scheme. Every one came at his own expense, and the first engineers of Europe were there. Over one hundred persons were present, the élite of the entire engineering world. We were divided up into sections, one on engineering, one on navigation, one on statistics, one on the movement of commerce, and one on finances. Each committee commenced its work without wasting any time. I said we should go to work *a l'Americaine*. "How is that?" they asked. "Quickly," I said. And after what I saw yesterday, I can say that I never before knew fully what it was to speak of anything being *a l'Americaine.* Now I know what it is when I see your bold street elevated road and your magnificent bridge and your other works of freedom in science.

At it we went for fifteen days, night and day. All our deliberations were afterward printed. I remember that in connection with the Congress something was said to the effect that the American delegation was not treated with due consideration. This was an erroneous idea. Admiral Ammen was made First Vice-President. I do not think any discussion was started that the Americans were not in courtesy first called upon to speak upon it, and when it came to the final vote, every man could vote as he pleased, and also give in writing his reasons for the vote. There was not only no disfavor shown the Americans, but I was even charged with showing partiality to them, and this charge will be found in the printed report of the proceedings. At the final vote, 78 voted for the Panama route and 8 against, 12 declining to vote. I did not expect until the last day to occupy the place I now do at the head of this gigantic work, but when I heard the exclamations of the Congress, and saw there before me, as I see it now, the face of my wife, I felt that I ought to put myself at the head of this work, and the completion of the circumnavigation of the globe.

I thought, moreover, I had not the right, after having gone so far, to refuse to see the work through. It would have been cowardice not to continue, so I advanced in spite of the opinion of Mme. de Lesseps. It has brought now the pleasure of a visit to America, and the enjoyment of the hospitalities which are now showering upon me, and which I should not otherwise have enjoyed.

The first thing after this was to get the concessions from the Compagnie Civile, which that body had secured from the State of Colombia. My plan was to offer the company $1,000,000 in cash when the subscription for our undertaking should be taken up, and $1,000,000 in the stock of the new company. This new company has not succeeded, partly on account of the opposition of the press, and the press is a great power and deserves to direct public opinion when it is managed by honest men. The subscription was not a success, and I paid back the money to all who had subscribed. Thereupon some of my friends came together, and placed $400,000 in my hands to enable me to verify the surveys, and to pay the deposit required by the Colombian Government. I could not have done this with my own means. I am not ashamed to say that I have no fortune. I have passed twenty years in diplomacy and thirty years in engineering, but I did not profit by any of the enterprises which I began. It is not my trade; I make it a principle not to gain anything from others. I have only the shares which I pay for myself. Those who invested their money in the enterprise have taken a great risk and have a fair right to the fruits of success. Now my work has commenced of executing the enterprise. It is a work of the entire world, not only for other nations, but especially for America.

Let us talk of the technical part. Determined to make a verification of former surveys upon which I had based my scheme, I repaired to Panamá with a party of ten well-known engineers. The expedition to the country has been safely accomplished, notwithstanding the dangers forboded to us. Much has been said against the climate of Panama; but we did not suffer from it at all. The climate of Suez is infinitely worse. The heat at Panama is from 23° to 33° Centigrade; at Suez 30° to 35°. We all came back in safety. The country was not dangerous at all, and was much more favorable to such an undertaking than that surrounding the Suez Canal, which I will now tell you of. The most celebrated engineers of France and England did not expect such a great success. I was treated as a fool because I simply desired to cut away the earth, whereas they had expected I would make a canal with the assistance of the Nile. I took engineers there and we occupied the territory. There was no water near, no houses, and it was nothing but a great plain of sand, containing nothing that could be of use to us. We used camels, and our laborers were divided in companies, some going in search of water while the others worked. There are no rains at Suez; it never rains there. The difficulties were almost insurmountable. There were battles with workmen, water had to be carried sixty leagues, we had fierce storms to encounter, and for the first two or three years we scarcely got a foothold. The sand did not frighten me as it did the public. It did not take much trouble to remove it, of course, and most of it was done by hand, before we had machines. But the taking out of clay was a more serious undertaking; in some respects it was more difficult to deal with than stone, because it could not be blasted or removed in blocks. Suez was far worse than Panama can be. We remember how we were told most solemnly that Suez could not be built, but we went, I shall say again, *a l' Americaine*, and did it, and now we propose to do it again. I have shown you the difficulties at Suez; at Panama there are no such difficulties.

Now (referring to a model in relief, of the proposed line of the Panama Canal), I will briefly sketch the route for the canal: It begins on the Atlantic side, at Colon (Aspinwall), and joins the valley of the River Chagres, a little south of the bay of Limon. The River Chagres however, does not empty into the Bay of Limon, but into the sea at the old town of Chagres. The canal follows the valley of this river to a point near Matachin, where the river has a sharp turn towards the north-east, and runs between two mountains. Here the canal leaves this valley, and it is proposed to construct a dam between these two mountains to provide for the storage of the flood waters of the river. This dam will be forty metres in height, and will retain about one thousand millions cubic metres of water. There are at least three dams in the world, which are of equal magnitude with this, and which have stood for many years; one in Spain is higher, and has endured three centuries.

The canal, leaving the valley of the Chagres, cuts through the mountains at Culebra, where the extreme depth of cutting will be about 270 feet, almost exactly the same as that of the towers of your great Brooklyn bridge, which you have just kindly shown us. Thence the canal will follow the valley of the Rio Grande to the Pacific, which it enters near the City of Panama.

Another advantage possessed by the Isthmus of Panama over that of Suez is its fertility, being a perfect paradise; there is no botanical garden in the world which could surpass it in beauty. The stations on the American railroad are surrounded by villages, and there is plenty of game in the mountains. I leave to the engineers with me the explanation of the details of the proposed plan, who will report as to the country which they have passed through, and after they have finished I will be at the disposal of the public to respond to all questions which any one may choose to ask.

Now, I beg to present this model to the Society of Civil Engineers, and to thank them for this opportunity of addressing you.

Discussion by J. Dirks.*

In the first place I beg to call your attention to the fact that neither

* Chief Engineer of the Canal from Amsterdam to the Sea.

the English nor the French is my native language. For this reason I invoke your kindness in overlooking any mistake as regards pronunciation; also grammatical errors. M. de Lesseps, the great mind who pulled down the Suez barrier, and therefore deserved, as well as earned, the thanks of mankind in general—came to America with the object of removing a second barrier, in joining together both oceans by a great ship canal through the American Isthmus. Allow me, ladies and gentlemen, to explain, in a few words, why M. de Lesseps deemed it convenient to invite me to join, not alone the Paris Congress of May last, but the scientific and technical survey of the canal line between Colon (Aspinwall) and Panama, which took place during the last few weeks. I have the advantage of being the engineer of the ship canal going from Amsterdam to the sea, which canal is fully described by your esteemed countryman, General Barnard, and was visited as well by himself as by other engineers of this great country, among them Captain Eads, the renowned builder of the St. Louis Bridge and of the wonderful works at the mouth of the Mississippi. When the general plan of the Amsterdam Canal was proposed, about 1860, only very few engineers believed in its feasibility, and the majority of scientific men were of opinion that a sea harbour in the shifting sands of the broad and shallow beach at the North Sea, as well as the dredging of a canal in the very soft mud of the lake through which it ran, were to be considered as quite impossible. Belonging to the small minority who were convinced that the Amsterdam Canal could be made and would fully answer the purpose, I was charged with the execution of the whole, in conjunction with Sir John Hawkshaw, from London, who acted as consulting engineer.

It is a great satisfaction to me that the Amsterdam Canal has been constructed; that the dark forebodings of a large majority never were realized; that the canal, at a cost of about $16,000,000, is a complete success, and that the largest vessels, even to a draught of twenty-four feet, easily enter and leave the new North Sea Harbour and get to Amsterdam within four or five hours. If not for the results of this proportionally smaller, but nevertheless very important scheme, M. de Lesseps would very likely never have known even my name. I have to thank him here for his kind opinion regarding the little experience in canal matters that I may have got, and I beg to state at the same time, as recorded above, that I was not alone in my quality of acting chief engineer, but that the great mind of my friend, John Hawkshaw, was there also, in order to avoid or to put aside many difficulties of planning and construction. As regards the technical possibility of a level ship canal between both oceans at Panama, I am happy to say again what I told a few days ago to some very competent men, namely, that I would like to write down my very favorable opinion in very large characters and put at stake my reputation as an engineer that the difficulties of this enormous work will be not greater—perhaps even less important—than those of the Suez Canal and of so many other great works completed with full success in America and in Europe. I want to state that the making of a deep cutting is just as possible at Panama as in the United States; that the blowing up of rocks may be done there even with greater facility than at Hell Gate, near this city, and, finally, that the only serious technical question to be solved is that of the floods of the River Chagres, through the alluvial and present bed of which a great part of the ship canal will have to be led. But even that difficulty can be surmounted. The result of the studies of Colonel Totten and Mr. Dauzats, who went into the question with the utmost care, was set forth in the international report recently published, and known, as I presume, to the members of this scientific body. I may therefore confine myself to the renewed expression of my heartfelt thanks to the chairman and the members of the American Society of Civil Engineers, as well as to many other citizens of this great city. They show their regards and kind sympathy not only for the engineer but also for the Dutchman. They talk feelingly about the old ties between my country and the United States. The same old blood is running through the veins of many on both sides of the Atlantic, and what happened in past times may lead toward what may occur in the future, the relations between both peoples and the other nations will be progressing for ever, and each barrier pulled down on the broad way of commerce and industry will largely contribute toward such a blessed prospect.

O. Chanute.—M. de Lesseps is now prepared to answer questions, and I will begin by asking him, what are the estimates of the probable cost of the undertaking, and the probable returns?

M. de Lesseps.—One hundred and sixty-eight millions of dollars. Of this $20,000,000 are for the large dam to keep the waters of the River Chagres in. It would not be necessary to have the work entirely completed before vessels could be sent through. I am satisfied, too, that the final operations will show a considerable reduction. This is the reason that induces me to fix the capital at 600,000,000f. or $120,000,000. But should my hopes in this direction not be fulfilled, the difference necessary to make up the estimate can be supplied by bonds or otherwise.

According to the returns of the Congress at Paris, it was calculated by M. Levasseur, the Chairman of the Committee on Statistics, that 6,000,000 tons would pass through the canal in a year, and that within ten years they would rise to 7,250,000. At Suez the tariff was 10 francs or $2 per ton, but at Panama it could be raised to $3, which would give a gross yearly revenue of $18,000,000, which would be a very large return for a capital of $200,000,000, which is much more than the canal is estimated to cost, including the running expenses and the interest on the money. And as this tonnage is greater than that which was estimated to pass through the Suez Canal, the canal on this continent would be a better investment than the other, and the stock and bonds of the Suez Canal are very much above par.

O. Chanute.—What proportion of the necessary capital will be raised in Europe, and how much do you propose to raise in this country?

M. de Lesseps.—The original capital will be $120,000,000. One-quarter has to be paid up before a company can be formed under the French law. One-half of the capital stock will be allotted to the United States, and the other half to Europe. But in case it is not taken up by the United States I will try and have the sixty millions taken up in some other way. But I wish to have it understood that one-half the stock may be subscribed for in the United States, as the United States have an interest in the enterprise equal to all the rest of the world put together.

Horatio Allen.—Past President of the Society:—I would like to ask a question, so that we may have a little clearer conception of the subject. I understand that the length of the canal from ocean to ocean will be forty-five miles; that a certain portion of that canal will be a deep cut, and that a certain other portion will be ordinary canal work. I would like to ask how many miles are to be cut through, and how many will be a deep cut?

V. Dauzats.—The deep cutting extends for about six and a half or seven miles. The deepest excavation will be about ninety metres; and for this distance of seven miles the cutting may average about 180 feet. In other parts of the canal the cutting will not be of very great depth.

Horatio Allen.—Is the deep cutting entirely in rock?

V. Dauzats.—Not entirely in the rock. There is earth over the rock. Col. Totten thinks that the earth may be twenty feet in depth, but in order to be safe the estimate was based on a depth of earth of twelve feet and the remainder rock.

Q. A. Gillmore.—Will you give some details as to the proposed dam for the Chagres River?

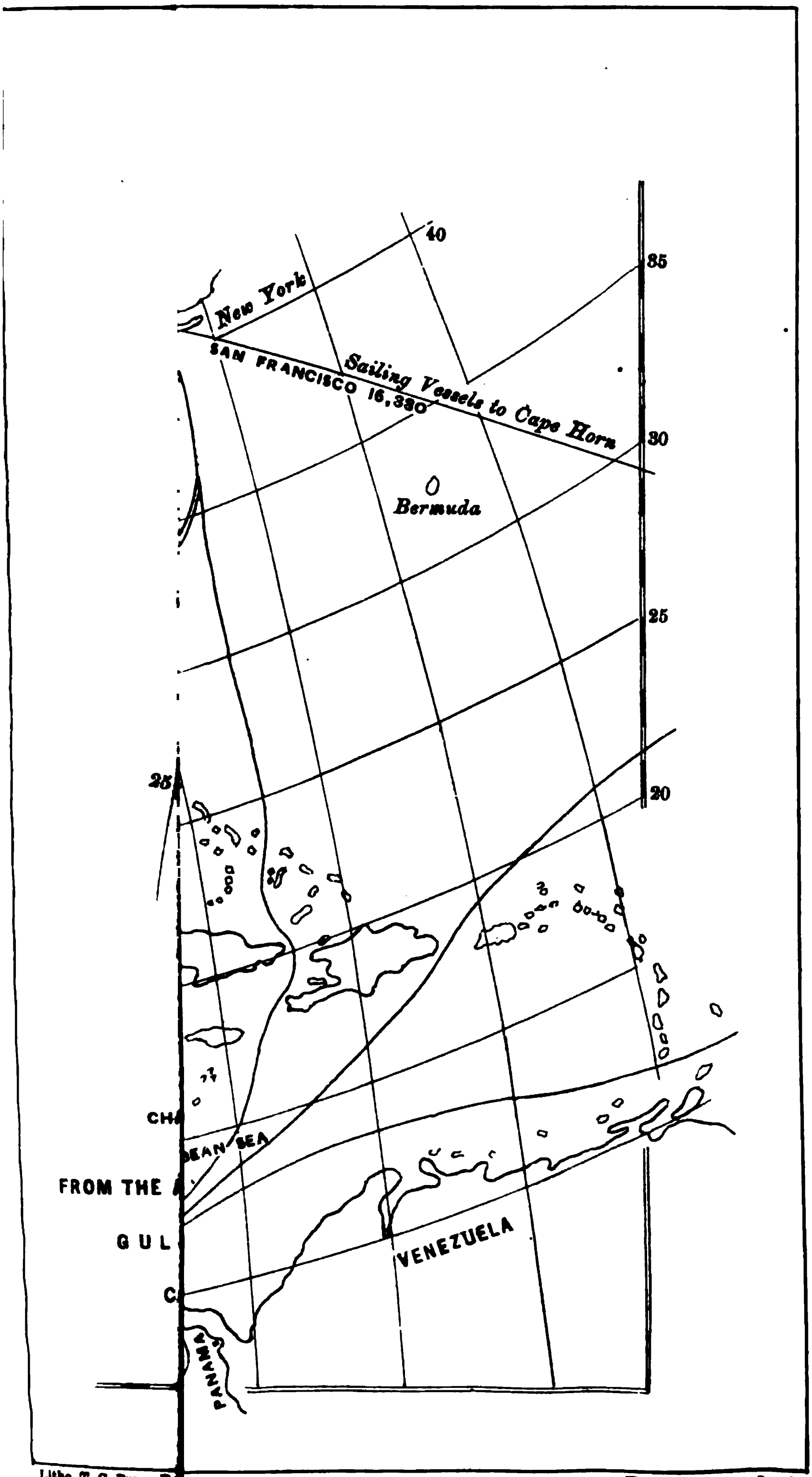
J. Dirks.—The height will be 40 metres and the length 1,600 metres. It will form a reservoir capable of holding more water than the greatest flood known on the river. Before a second flood arrives the reservoir could be emptied by the main and the secondary canals. The dam can be sufficiently well built to make it perfectly safe.

Ashbel Welch.—Why go to the enormous expense of making a sea level canal across the Isthmus when a canal with two or three locks on each side of the deep cut could be made so much more cheaply?

M. de Lesseps.—If the Commission of Engineers which had gone down to Panama had reported in favor of a canal with locks I should have put on my hat and left the whole project and would have had nothing to do with it. That plan may do for small ships, but when we have vessels now afloat 500 feet long and others on the stocks 600 feet long, it is impossible to say for what you would have to build the locks. Single locks would be slow, and double locks though quicker would be very expensive and require constant repairs. At Nicaragua they intended the use of locks, and with the earthquakes which prevail there the repairs would be ruinously expensive, and even at Panama, where earthquakes do not exist, they would be fatal by reason of the loss of time. I would not have anything to do with a locked canal except for little ships. It is not the proper idea for a grand inter-oceanic canal.

C. Butler asked why the San Blas route has not been examined.

M. de Lesseps.—The object of the Commission was to examine the line accepted by the International Congress; but in reference to the route referred to by the gentleman, I would say, that although the port on the Atlantic side is very good, that on the Pacific side is not. This line would make necessary a tunnel of, say, seven miles in length, and as the Commission had already rejected a route in which there would be a tunnel of three or four miles, why adopt one having a tunnel so much greater in length?



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No. CCCXXIX.

JAMES CLEMINSON'S "FLEXIBLE WHEEL-BASE" OR RADIATING AXLES.

[*Vide* Plate].

As carriages are now being fitted on this principle on the Scinde, Punjab and Delhi Railway, the following extract from the *Engineer*, February 15th, 1878, may be interesting. The plan seems to have been extensively tried in England, America and the Continent of Europe, during the last three years, and to have met with very general approval, and to work practically perfectly up to curves of 70 feet radius.

It is not clear from the description or figures how "the central axle is at liberty to slide under the main frame" of the carriage, but this is a matter of detail. The main frame probably rests and slides on the corner plates shown on each minor axle frame, and the only other connection is the two swivel pins of the end frames.

"Though the desirability of using some arrangement of the under carriages of railway rolling stock, by which the axles would be free to depart from rigid parallelism when traversing curves, has been felt for many years, it is only recently that much has been done in this direction as regards passenger coaches in this country. Previously all the stock, and even now on most of our lines practically all was, and is, fitted with wheels whose axles are rigidly parallel, a condition which could not have been allowed to exist so long had it not been possible to obtain the requisite engine power and strength of the parts of the vehicles and permanent way which such a system of construction entails. On a straight line a vehicle with parallel axles may be considered to need very little guidance by the flanges or rails; the tendency of such a vehicle in motion is to pursue obstinately a straight course, and from it is only caused to depart by side pressure on flanges and rails. The intensity of that pressure may be imagined when the amount of skidding on any curve is remembered. For instance, a train passing round 90° of a curve of, say, 10 chains radius, is actually *skidded* through not less than 60 or 70 feet; the actual amount of skidding depending to some extent upon the length of the vehicles. The Americans first endeavoured in a practical manner to remove this defect by the application of the bogie, but even that very useful invention only partly removes it, as each bogie is in itself a vehicle with parallel axles, but with a short wheel-base. It is only recently, however, that even a bogie has been much used in this country, though it has for several years been known that long carriages run much more steadily than those of the ordinary length, and the proportion of dead weight, or non-paying load, may be made to decrease with increase of length. Carriages of increased length have been built, most of them running on six wheels with parallel axles, a certain amount of transverse play being allowed in the central axle. Even with this, however, the position of the wheels on a sharp curve is as illustrated in diagram, *Fig.* 4, from which the tendency of the wheels to mount the rails, and the increased power necessary on a curve as compared with a straight line, to pull such a carriage along, may be estimated. By the use of the bogie the strongest objections to long carriages have been overcome, but others have been imported by which the object of using long carriages has been partly defeated. The bogie car being supported only at or near the ends, its motion is little better than an ordinary short carriage, while the distance between the supports involves the use of very strong and heavy framing, and the bogies of themselves are of such weight that the paying proportion of the load, instead of increasing with the increased length, has in most instances decreased. The parallel axles of the bogies have, moreover, the objections which are attached to short carriages with such axles, so that, although it, as far as itself is concerned, permits the construction of long carriages, the grinding and waste of power on curves is as great as with ordinary short carriages, for the direction of pull of the long carriage on a curve causes a thrust on the inner rail at the foremost end and on the outer rail at the rear end.

"Our object here is to place before our readers a system of construction invented by Mr. James Cleminson, of Westminster, which overcomes these difficulties in a satisfactory manner, its chief recommendation being that while securing other advantages it provides the means of passing round the sharpest curves with the axles always normal and radial thereto, whatever its radius, as shown in *Fig.* 5.

"This result is achieved by so attaching the axles to the carriages and to each other as to permit them to adapt themselves automatically and with perfect truth to the varying conformations of a railroad. This is effected as follows:—The axles, with their axle-boxes, guards, and springs, are mounted in frames BCD, *Figs.* 1* and 2, separate from the main underframe E. The end frames B and D have central pivots H, around which they swivel freely, whilst the middle frame C is at liberty to slide transversely to the main underframe E through a range equal to the versed sine LM of an arc NLO, the chord of which equals the wheel-base NMO—*see Fig.* 6—and finally the frames are connected to each other by the articulated radiating gear IK. The action of the combination is simply thus—When a vehicle enters a curve, the middle axle and frame C move transversely through the versed sine of the wheel-base arc, and, in doing so, cause the end axles and frames B and D to swivel around their pivots H, so that all the axles assume positions of radii of the curve.

"There is, it will be noticed, nothing of a special nature, beyond the axle-frames, required in the application of the invention, either in building new carriages, or converting old stock, these frames entailing very little extra cost, for as the main underframe E is relieved of the strains ordinarily due to curves, it is said that it may be reduced in strength to such an extent as to compensate for the cost of the axle-frames. All standard fittings, such as axle-boxes, guards, and bearing springs, are retained without alteration.

"It will be seen that the system permits the construction of vehicles of any length, and secures the unattained objects of the bogie with the advantage of support throughout the length of the carriage. In very long carriages, say 80 feet, eight wheels would be employed, with a modification of the arrangement illustrated.

"The carriage illustrated by *Fig.* 1* is the new Royal Saloon carriage constructed by the South Western Railway Company, and was briefly described in the *Engineer* of the 30th of November last. Brief reference to the steadiness and ease with which the carriage passes round sharp

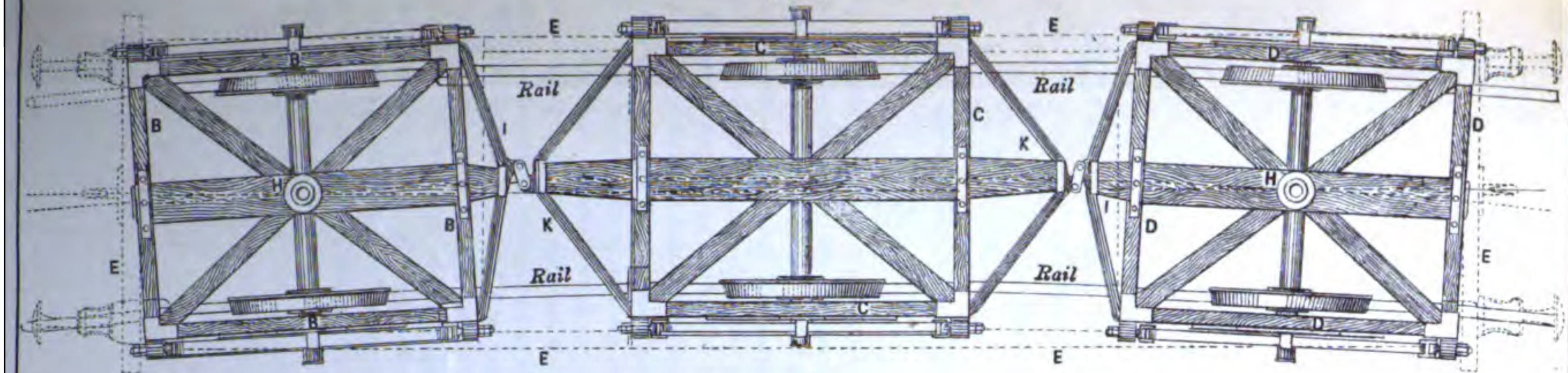
* Not reproduced.

curves was made on page 75 of the current volume. Carriages on the system described have been running for about a year on the London, Chatham, and Dover Railway, and any passenger travelling from Chatham to London will be able to make the journey in the old and new carriages, and prove for himself the great difference in the comfort of the two systems, especially when travelling by the boat express from Chatham to Herne-hill. The line is notoriously crooked, but it is on such lines that the new carriages show their great superiority in steadiness and smoothness in running.

"Besides being in use on the lines referred to, a number of pairs of short Metropolitan carriages are being converted into single long carriages on the new system by splicing, and a large quantity of stock is running on the Campanhia Paulista Railway of South America. Several English companies are making up whole trains, and a somewhat remarkable example of the application of the system is its use on the North Wales Narrow Gauge Railway. The gauge is 1 foot 11½ inches, and an official trial of a whole new train was recently made at a speed of twenty miles per hour, which, on a line which may be almost considered as a continuous set of curves of two chains radius, would be attended with the greatest danger with any other stock. The stock has hitherto been of the bogie class, the carriages being 25 feet in length, carrying 30 passengers, and weighing 5½ tons. The new carriages are 30 feet long, carry 42 passengers, and weigh 4½ tons each. The latter have thus 33 per cent. more accommodation and weigh 20 per cent. less than the former. The bogie carriages rock very much in passing round the two chain curves, but this is not the case with the new carriages, which have a wheel base of 23 feet, or more than one-sixth the radius of the sharpest curve. The economy in weight in this instance is, it will be seen, very great, and is illustrative, for though on the stock of full size railways the gain is not so much, it is very large in all cases. In proof of the merits of the system, we may point out that it is being regarded with much favour by many locomotive and carriage superintendents, who are necessarily not the least easily satisfied. The facts that the carriage is so thoroughly supported throughout its breadth and length, and that the existing frames, springs, hornplates, &c., are all applicable, as well as the general simplicity of the arrangement, very strongly recommend it."

JAMES CLEMINSON'S "FLEXIBLE WHEELBASE," OR RADIATING AXLES.

Fig. 2.



PLAN OF AXLE FRAMES ON A CURVE OF 100 FEET RADIUS

Fig. 6.

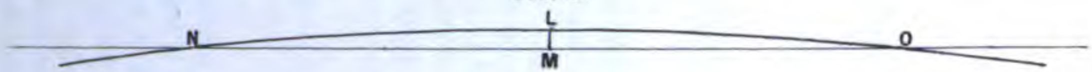


Fig. 4.

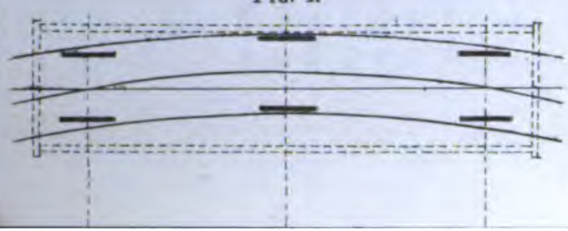
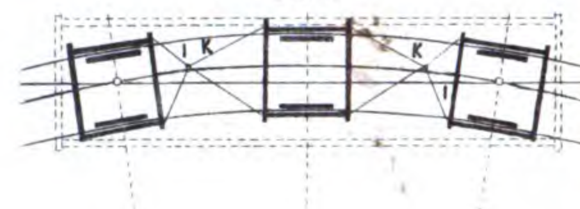


Fig. 5.



No. CCCXX.

CLIP CALLIPER FOR LIFTING WASTE WEIR PLANKING.

[*Vide* Plate.]

BY A. HAYES, ESQ., *Assistant Engineer, Cossye Division.*

THE accompanying drawing represents a clip calliper for lifting waste weir planking, designed by Mr. E. Raynean, Sub-Overseer, Cossye Division, formerly Dehree Training School Apprentice. During irrigation season, when it is necessary for the regulation of the supply to the various reaches to the pretty constantly raising and lowering the planks on the canal calingulahs, it has hitherto been necessary to send a khallasy down into the water to attach the loops of the lifting ropes to the wooden pins, driven for this purpose through each end of the planks, and this has been always rather a hazardous proceeding.

The present arrangement obviates any such necessity, for two khallasies standing on the one bridge each with a calliper, can grip the planks and raise or lower them as may be desirable.

The following description of their action, in addition to the plan, will clearly explain the method of working the calliper.

Raising.—The two jaws of the calliper weighted at the upper extremities with two cylindrical weights when opened out for the purpose of gripping a plank, are retained in position by a bent hook catch A. The calliper is provided with two sockets BB, in order to allow of its being attached to, and sliding on, a guide rod. When used in still water the guide rod is not required, and the calliper can be lowered fairly on to the plank, attached to a rope, but in an overfall of 2 to 4 feet or more, the use of the guide rod is indispensable. The guide rod is provided at its lower end with an elbow iron point, which, as the rod is carried down by the stream, catches on the face of the planking, and allows of the rod being brought to a vertical position in the current.

The rod being dropped well ahead of the planking and brought vertical (*Fig.* 1), the calliper with jaws open and set, and the upper catch inverted, is lowered by a line down the rod until the convex portion of the bent hook A, coming in contact with the planking the catch is freed, and the jaws close in an immoveable grip, the calliper assuming the position of the dotted lines. Both rod and calliper can now be hauled up with the plank or the rod detached, and the calliper and plank raised.

Lowering.—When it is desired to lower a plank, the plank is gripped as per *Fig.* 2, and the calliper lowered, the upper catch C being slipped up above its notch. On the plank reaching its place, the lowering rope is slackened, and the upper extremities of the jaws opening the upper catch C falls down into its notch, retaining the jaws open and the plank is freed, the calliper assuming the position of the dotted lines. It is generally found in a current that an additional blow or two with a rammer from above is necessary to overcome the friction of the plank against the grooves and drive it fairly down.

The main dimension and weight of a calliper is as follows :—

	Weight.
Jaws, flat iron (over all) 1' 6" × 1½" × ¼"	
Sockets, pins and other parts, ...	8 lbs.
2 Leaden weights, ...	7 „
Total weight of calliper,	15 „

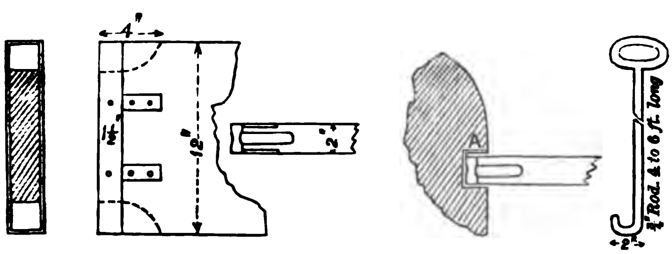
Rod 15' × 1½" × 1½".

The dimensions of the calingulah planks are 5' × 1' × 2½". The head lock stop planks to prevent silt getting into the lock in flood time, dimensions 20' × 6" × 4" are also lifted with a pair of callipers. The planking should be slightly notched to enable calliper jaws to obtain a securer hold.

A. H.

Editor's Note.—Practice with a simpler tool, see *Fig.* A, produces a fair result. The Dadupur dam, West Jamna Canal, over the branch of the Jamna, has 60 openings of 10 feet breadth, 4 to 6½ feet deep, closed by about 290 planks. On approach of flood, about 230 of these are taken out and carried to banks by 45 men in two hours. The carrying is of course the heavy work requiring the number. Only 8 men are employed in lifting planks. The lower planks are of course lifted under 4 to 6 feet head and rush of water. Two hours is the night time, one and a half is sufficient in day light. This is rather smart practice, and I enter

Detail of end of plank at A.

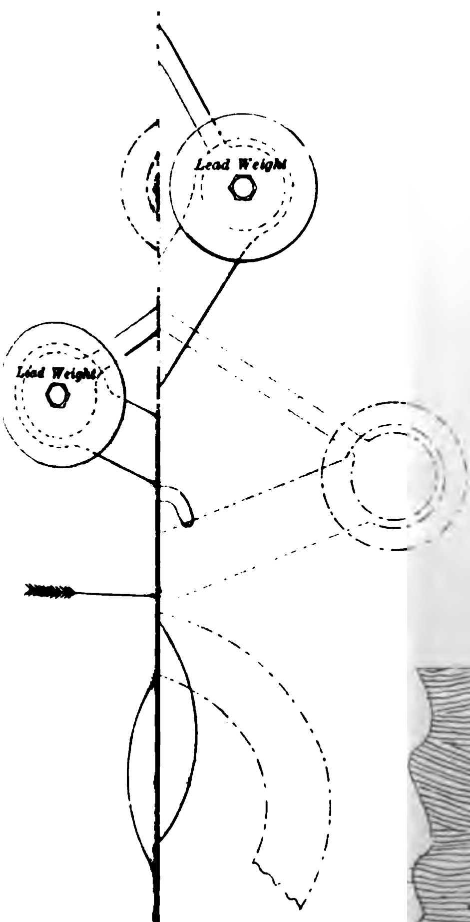


it here more as a bit of information as to what can be done, than to detract from the invention alongside. This is useful in cases of very deep water where a rod would be long and unwieldy, but the fact that the catch on the plank is *in* the groove in the pier makes it easy to find.

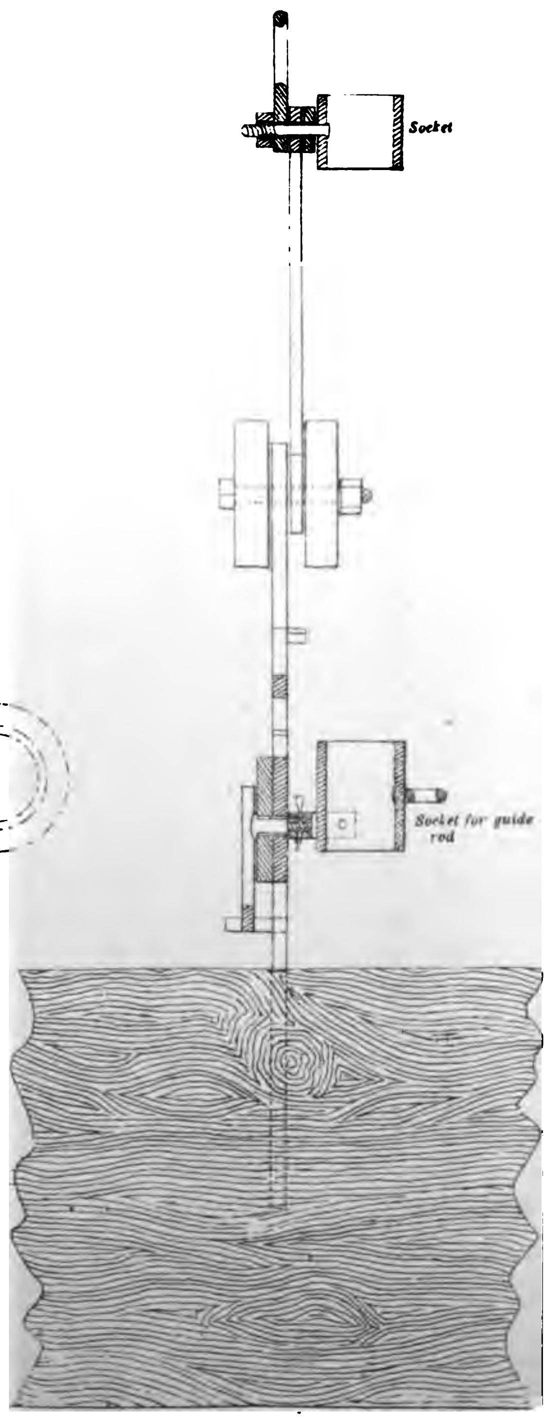
Fi

POSITION

The dotted lines thus —
position of the Callipers
being released by the
on plank the claws take



SECTION THROUGH A B.



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THOS. D. BONA, Supdt.

No. CCCXXXI.

ELECTRICAL INTER-COMMUNICATION IN TRAINS.

[*Vide* Plate].

By G. K. Winter, Esq., F.R.A.S., M.S.T.E., *Telegraph Engineer, Madras Railway.*

Amongst the numerous applications of Electricity, the rapid communication of intelligence from one place to another is that which has received the greatest development, and it is certainly the use to which this wonderful agent appears to be most specially adapted. In the early days of its employment for this purpose it was thought uncertain and capricious, but as time went on, difficulties one after another disappeared; its action, before uncertain, became more and more under control, and its very caprices have been found subject to law, and have been converted into some of the most useful of its attributes.

Inter-communication in trains, or the communication of intelligence from one part of a train to another, has received a large amount of attention, and much ingenuity has been devoted to the solution of the problem. The fact, however, that no system has been universally adopted would tend to show that no system hitherto brought forward is practically perfect. Captain Tyler has said that electricity offers the best promise of success, and in this view most men acquainted with the present state of electrical science would probably concur.

In looking carefully into the question of the merits and demerits of the various existing electrical methods, with a view of discovering the best system for adoption on the Madras Railway, I found that the use of the wheels and rails as an " earth " or return circuit, and the use of special electrical couplings, were nearly universal. A few experiments were sufficient to convince me that in India, at least, we could not make this use of the wheels and rails, for even supposing the electrical contact between the framework and the axles to be perfect, that between rail and rail could not be relied on, especially in dry weather; and with regard to the special electrical coupling, a little consideration was sufficient to show that any system which involved any extra labor or attention in forming or shunting trains, was unsuitable to our mixed and ever-changing traffic. There seems also to be little doubt that any difficulties which have been found to attend the application of the electrical systems hitherto proposed have been due to negligence or forgetfulness in forming the extra coupling, or to the imperfect earth formed by the wheels and rails; a coating of snow for instance over the rail would destroy communication even in England. The motion and consequent vibration of a train, on the contrary, presents no difficulty which cannot be easily overcome.

My endeavours have therefore been directed to the adaptation of the existing couplings to the purposes of communication, and to doing away with the necessity of using the wheels and rails as an earth. The result is a system which has been well tried on the Madras Railway, and has, I believe, given satisfaction to all who have seen it. It is impossible for any mistake to be made by the porters in forming or shunting a train, for they haye only to do the work they have been always accustomed to, and it is impossible for any quantity of dust, tar, dirt, or grease on the surfaces of the hooks to damage in the slightest degree the integrity of the circuit, for the hooks are self-cleansing, and the weight of the chains is sufficient to insure the perfection of the contact.

Having abandoned the use of the wheels and rails as an earth, we require two conductors, insulated from each other, running from one end of the train to the other. This is simple enough as far as the carriages themselves are concerned, but the most difficult as well as the most important point is the mode of connecting electrically the conductors of one carriage, with the corresponding conductors of the next. This connection I accomplish by means of the side or safety chains in the following way:—

A strong and flexible cable is passed through the links of the chain; the conductors of this cable form a continuation of one of the insulated conductors of the carriage, and are fastened electrically to the hook at the end of the chain.

The cables are made by winding galvanized iron binding wire, weighing about 100 lbs. to the mile, helically round 1½ inch tarred hemp rope, in the grooves between the strands. The end of this cable, which is to be attached to the hook at the end of the chain, is close bound with the same binding wire for a length of about 3 inches, and the ends of the wires projecting beyond the hemp rope are twisted together into a wire rope.

Two holes are drilled through the shank of the hook about 1½ inches apart, and into these holes tinned iron eye bolts are soldered. The ring of the eye bolt nearest the end of hook is only large enough to admit the wire rope projecting beyond the cable, while the other is large enough to admit the cable together with the extra binding. The bound end of the cable is passed through the large eye bolt and carried as far as the small one, through which the wire rope is passed, and to which it is firmly soldered; the rope is then unwound and spread radially over the ring of the bolt, and again firmly soldered on to its surface, the ends of the wire being cut off if too long. The lower end of the cable being thus firmly fastened to the shank of the hook, the cable is passed through the links of the chain in the most convenient manner, and finally passed through a hole in the buffer plank of the carriage, the wires of the cable are then soldered to the end of one of the wires running underneath the vehicle. The chain and cable are well coated with tar, except on the inner surface of the hook.

The next point to be considered is the best mode of securing good electrical contact between the hook of one chain and that of the next carriage, when they are coupled. On the electrical condition of this contact depends the success or failure of the system, I have therefore spared no pains to ensure its perfection. The shape of the hook is first altered from the ordinary form shown in *Fig.* 1 to that shown in *Fig.* 2. To secure uniformity and correctness of figure, a steel or iron die is made of the shape shown in *Fig.* 3. The hooks are made red-hot, and are easily altered into the required shape by first driving the die between the jaws of the hook, and then completing the alteration by means of the hammer, keeping the die in its place during the operation. The bearing surface of the hook is then coated with a piece of sheet copper which is brazed on, and finally a small rib of gun-metal of semicircular section is soldered on to the inside of the outer jaw of the hook. *Fig.* 4 is a drawing of a complete chain with cable, &c., and *Fig.* 5 is an enlarged drawing of the hook with its copper lining, and gun-metal rib.

It has been found that with hooks prepared as above, neither grease, tar, nor dust, are able to impare the contact of hook with hook, and the small stones, which are occasionally thrown upon the chains from the ballast, are unable to insinuate themselves between the acting surfaces.

The method of working adopted on the Madras Railway is very simple, and might be still further simplified could a battery be conveniently placed on the engine.

A battery is placed in each brake van, and all batteries are so connected that they always tend to send a current in the same direction. The circuit is always open except when closed by pressing a plunger in the act of signalling. The disposition of the apparatus in a train will be understood from *Fig.* 6.

All that is necessary is to have a brake van between the passenger carriages and the engine, and even this rule would be rendered unnecessary, if we could place the battery on the engine, instead of in the vans. This system has been working exceedingly well on the Madras Railway, since the 1st January 1879, the daily train mileage worked being about 1,776 miles. The fitting of the whole stock of the Railway is being rapidly proceeded with, and at an early date the whole of the trains running on the Railway will be provided with an efficient means of communication between the Guards and Passengers and the Driver. The arrangements are tested on leaving or passing through each station, by the Guard in the rear van giving an all right signal to the Driver, and any failure or irregularity in the working of the apparatus is entered in the Guard's and Driver's Journals, and is reported to the Heads of their respective Departments, so that the letters that have been given me by the Traffic Manager and Locomotive Superintendent are written with full knowledge of the manner in which the system has worked.

It has not been thought necessary hitherto to apply a break-away signal to the system on the Madras Railway, and the author does not recommend its adoption, owing to the complication necessarily involved: it can however be applied in several ways, of which the following arrangement is probably the cheapest, simplest, and most easily applied.

The closed circuit is used, and signals are made by breaking or opening the circuit, so that if a train parts a signal is given automatically in consequence of the break in the circuit, caused by the parting of the train. The difficulty which has hitherto prevented this system from being adopted is that during shunting, or when the engine is separated from the train, the engine bell would be continually ringing, unless some act were performed to stop the ringing; and, in this case, there is always the danger of the apparatus not being re-adjusted for ringing, when the train is made up again. This difficulty I propose to overcome in the following simple manner.

A relay is used on the engine to complete the circuit of a local battery through the bell. This relay has two contacts, the armature making contact with the one when the train circuit is complete (that is when the constant current is flowing through the coils of the relay), and with the other when the train circuit is broken (that is when no current is flowing through the relay coils). A switch attached to the apparatus is arranged to join one contact with the battery and bell, when the switch handle is in one position, and the other contact with the battery and bell, when the handle is in its other position. Thus, suppose when the train is joined up, and the train circuit closed, the bell is silent when the switch handle is at A, and that it rings when the handle is at B; then, when the train is divided, and the train circuit broken, the bell will be silent when the handle is at B, and it will ring when the handle is at A. Thus on arriving at a station at which shunting is to be performed, directly the train is divided the bell will ring, and will continue to ring until the Driver turns the handle to B. Again, when the shunting is completed, and the train joined up again, the bell will ring until the Driver turns the handle back to A. So that, whether the train is being formed or broken, the Driver is reminded of the change to be made in the position of his switch handle, by the ringing of the bell, and there is consequently no chance of the proper adjustment being forgotten. The arrangement is shown in *Fig.* 7.

It will be seen that signals may be given to the Driver by simply dividing the circuit in any part of the train, and keys arranged to do this may be fixed in any or all of the vehicles. Also should any part of the train become separated, the act of separation will break the train circuit, and cause the bell to ring.

No. C $\frac{780\frac{1}{2}}{A. \& M.}$

From—H. E. Church, Esq., *Traffic Manager, Madras Railway Company.*

To—G. K. Winter, Esq., *Arconum.*

Madras, 9th October, 1879.

In reply to your enquiry as to our experience of the practical working of your electrical communication in trains, I have much pleasure in informing you that since its introduction, on the 1st January last, in the mail trains, it has worked most satisfactorily, and the comparatively few interruptions we have experienced have been found on enquiry to be due to carelessness on the part of the Train or Station staff, and not to any defect in the system.

The communication has been made use of by the public on more than one occasion, when a spark from the engine had set fire to clothes, or bedding, and there can be no doubt that it is much appreciated by the Train staff.

* * * * * * * *

No. $\frac{3224}{4626}$

From—F. H. Trevithick, Esq., *Locomotive Superintendent, Madras Railway.*

To—G. K. Winter, Esq., *Telegraph Engineer, Arconum.*

Perambore Works, 27th November, 1879.

In compliance with your request that I should express an opinion upon the working of your electric inter-communication apparatus, I have much pleasure in testifying to the success with which it has been worked during the last 11 months on this Railway.

The apparatus is now fitted to nearly all the engines on this line; it has done good service to passengers on the occasions when it has been needed by them, and as far as I know, has not once failed from any defect in the apparatus.

The bell on the engine always rings, and so clear and strong in answer to the Guard's touch on the key in his van, that it has often occurred to me that the use of the apparatus ought to be extended by the adoption of some simple Code, so as to enable the Guards to communicate much more than an order to stop, or a signal that all is right behind. It would be most useful as a starting signal, especially for long goods trains on dark and stormy nights.

As there is no machinery to get out of order; as it requires no special couplings between the vehicles, and admits of easy application to foreign stock mixed up in the trains, and as, above all, it has now stood quite successfully the practical test of a year's working, I have no hesitation in asserting it to be the best inter-communication scheme yet brought out.

Extract from a letter from the Agent and Manager, to the Secretary, Madras Railway Company, No. 1388, *dated the* 18*th of October*, 1879.

From the 1st of January last the mail trains have been provided with electrical inter-communication between Guards and Passengers and the Drivers, and since the 1st of February the 7 A.M. and 6-15 A.M. passenger trains have also been similarly provided, the working of which in all cases has been satisfactory.

G. K. W.

ELECTRICAL INTER-COMMUNICATION IN TRAINS.

FIG. 1.

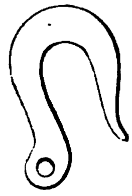


FIG. 2.

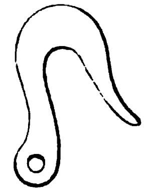


FIG. 3.

FIG. 4.

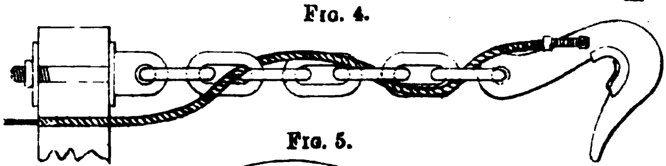


FIG. 5.

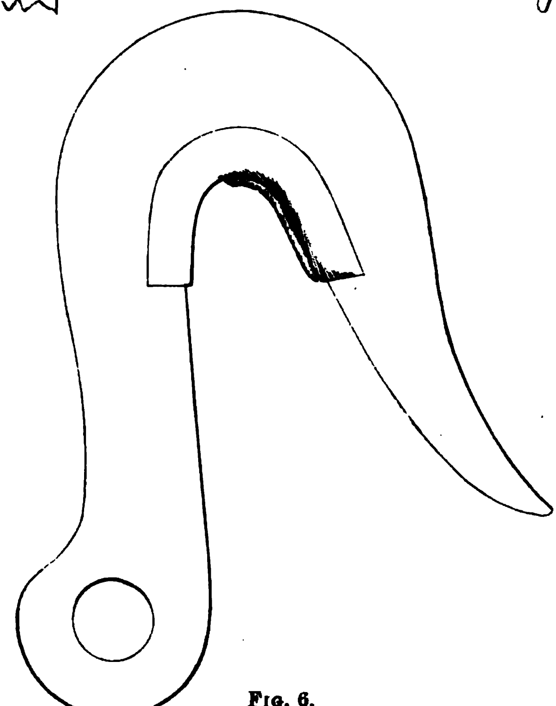
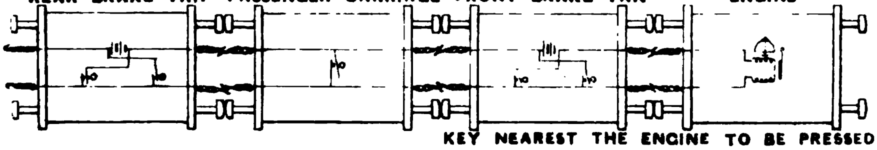


FIG. 6.

OPEN CIRCUIT CIRCUIT CLOSED BY PRESSING KEY

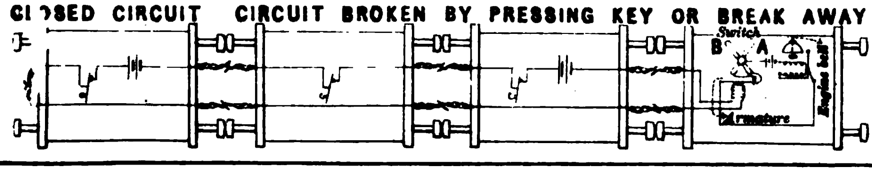
REAR BRAKE VAN PASSENGER CARRIAGE FRONT BRAKE VAN ENGINE



KEY NEAREST THE ENGINE TO BE PRESSED

FIG. 7.

CLOSED CIRCUIT CIRCUIT BROKEN BY PRESSING KEY OR BREAK AWAY



ELECTRICAL INTER-COMMUNICATION IN TRAINS.

FIG. 1.

FIG. 2.

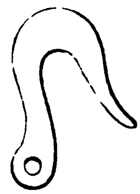


FIG. 3.

FIG. 4.

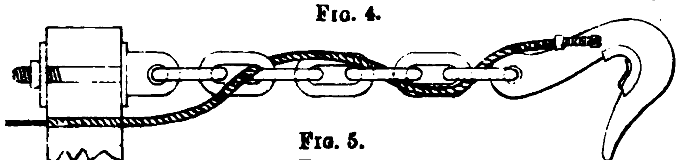


FIG. 5.

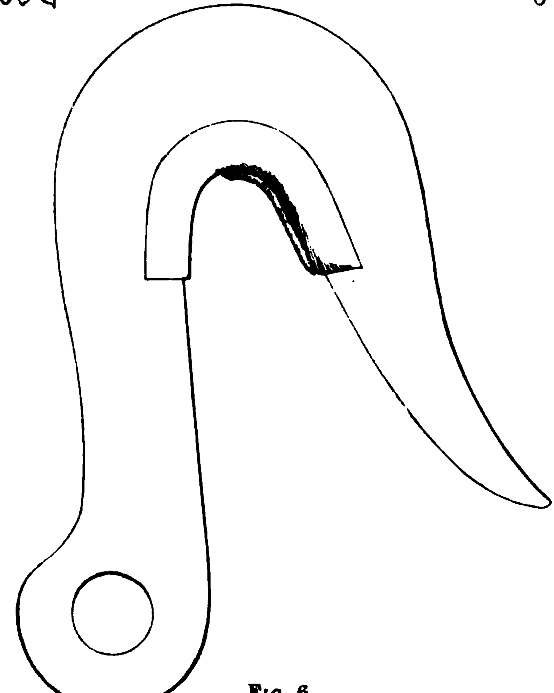
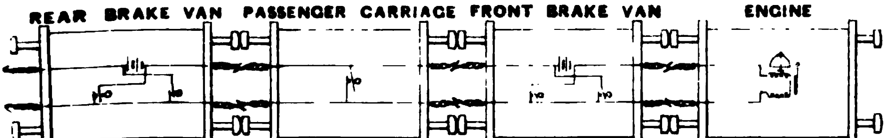


FIG. 6.

OPEN CIRCUIT CIRCUIT CLOSED BY PRESSING KEY

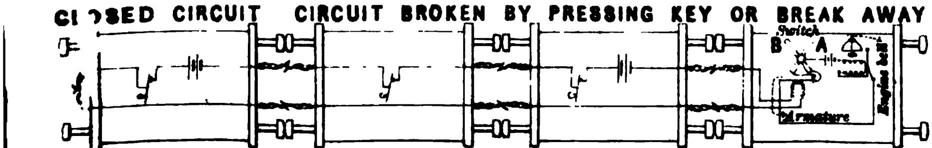
REAR BRAKE VAN PASSENGER CARRIAGE FRONT BRAKE VAN ENGINE



KEY NEAREST THE ENGINE TO BE PRESSED

FIG. 7.

CLOSED CIRCUIT CIRCUIT BROKEN BY PRESSING KEY OR BREAK AWAY



No. CCCXXXII.

ALFRED NOBEL'S DYNAMITE.

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

By Major J. L. L. Morant, R.E., *Executive Engineer.*

The supremacy of gunpowder as the only safe and economical blasting agent has for some time been a thing of the past. The advantage offered by explosives more violent in character has become widely known and utilized. Of all these explosives, those in which nitro-glycerine is the chief constituent have received the widest application. And of these latter, dynamite is the one which seems best adapted for India. It is now, and has for some years been, very largely employed all over Europe; and in some places has, for blasting purposes, entirely superseded powder, notwithstanding the greater care now bestowed upon the manufacture, and the improvements introduced into the nature and form, of powder.

Its increasing consumption.—In Europe, America and Australia its annual consumption is now considerably over 5,000 tons: and this consumption has been increasing since its introduction as follows:—

Year.	Tons.
In 1867, ...	11
„ 1868, ...	78
„ 1869, ...	185
„ 1870, ...	424
„ 1871, ...	785
„ 1872, ...	1,350
„ 1873, ...	2,050
„ 1874, ...	3,120
„ 1875, ...	4,000
„ 1876, ...	5,000

I have not been able to obtain the figures since 1876.

Gelatine Dynamite.—Nor has the *ultima Thule* in dynamite been yet reached: M. Nobel is now introducing a gelatine dynamite which has already, to an important extent, supplanted the Kieselgurh dynamite on the Continent of Europe. He has now discovered that a comparatively small quantity of a nitrated cellulose, prepared from cotton in a peculiar manner, has the property of transforming liquid nitro-glycerine into a gelatinous mass highly suitable as an explosive, possessing twice the destructive force of dynamite No. 1, at only 60 per cent. greater cost in the explosive. Gelatine dynamite is composed of—

Nitro-glycerine, ...	86·40	parts.
Soluble gun-cotton, ...	9·60	"
Camphor, ...	4·00	"
	100·00	"

It possesses the following extraordinary qualities:—

(i), It may be preserved intact for an indefinite time under water, so that it is even proposed to store it by keeping it immersed in water till required for use; (ii), it never gives off its nitro-glycerine even under extreme pressure; (iii), it is unaffected by violent shocks or vibrations and even by explosions which may occur close beside it, and (iv), it is not affected dangerously by fire.

Nobel's Dynamite, No. 1.—The blasting gelatine is not, however, in some respects, so suitable for Indian Engineering as the Kieselgurh dynamite, or Nobel's Dynamite No. 1, as it is called by the Trade. The following remarks will refer almost solely to the Kieselgurh mixture. They will be followed in a succeeding number by a record of certain special experiments carried out in India on the effective use of dynamite in rock blasting.

Advantages of Dynamite.—Dynamite offers the following advantages:—

1. Its explosive effect is much more violent than that of powder, and it requires fewer bore holes than powder does, hence saving in labour, tools, explosive, and fuze.

2. Not only is a much larger quantity of powder than of dynamite required to produce similar results; but it is often impossible to perform the same operations even with exorbitantly large charges of powder: this is especially the case in the breaking up of masses of hard rock or metal by the super-position or simple insertion into cavities of the dynamite.

It is hence invaluable on field service, or wherever work has to be instantaneously done (as in the case of a mountain road suddenly blocked against traffic by a storm), or wherever time is of greater importance than a larger expenditure of the explosive.

3. In hard rock the shattering and splitting effect of dynamite is much greater than with powder; and the rock is broken up to the bottom and sometimes beyond: it hence cheapens the after removal of the shattered rock, and is peculiarly advantageous in obtaining broken stone for roads.

4. Its density being nearly double that of powder, and its power very much greater, its bore holes can be made smaller than those for powder.

5. To a certain extent, and for limited periods, dynamite is unaffected by dampness: there is therefore no necessity to dry the holes as when powder is used, and it is also without difficulty usuable in water bleeding rocks.

6. The explosion of dynamite being instantaneous, almost any kind of tamping suffices; or, at least, tamping is not nearly so important in employing dynamite as it is in using powder. Water is often used as tamping; and in case of a miss fire this is extremely convenient, for the primer and fuze have simply to be withdrawn and another primer and fuze inserted.

7. Dynamite cannot be exploded by simple ignition: it must be exploded by violent detonation. Hence its great safety as an explosive. Even if its store be on fire, it will burn for a considerable time before it can explode. And though it can be exploded by a shock, this shock must be of such a character as it is very unlikely to meet with in practice. There is hence less danger in the transport of dynamite than in that of powder.

8. Dynamite possesses the advantage over gunpowder of producing, when fully and properly exploded, but little smoke; but if a hole be overcharged, or if the explosion be imperfect, then the vapours evolved from dynamite are more objectionable than gunpowder smoke.

9. The manufacture of dynamite is conducted with greater safety than that of gunpowder: though several thousands of tons of the former have been made in England not a single life has been lost among the numerous workers employed.

10. The few precautions required in using dynamite are perfectly simple, easily understood, and easily carried out.

11. English dynamite is not liable to explode spontaneously: no instance has ever occurred of its so doing. The following Table will make readers assured of this :—

The undermentioned articles give off an inflamable gas which forms an explosive mixture with the air at the following temperatures :—

	Fahrenheit.
Ether, ...	88°
Parrafin oil, ...	120° to 150°
Naptha, ...	150°
Alcohol, Brandy, Whiskey, &c., ...	170°
Benzol, ...	176°
Turpentine, ...	320°

Whilst the undermentioned articles explode spontaneously at the following heats :—

	Fahrenheit.
Dynamite, ...	400° to 420°
Gunpowder, ...	500° to 600°

12. In store the risk of an explosion of dynamite is almost *nil*.

Its only drawback.—There is one drawback in the use of dynamite, and that is that it freezes at a temperature 14° (Fahr.) warmer than the freezing point of water, and when frozen it thaws very slowly, and can only be exploded with difficulty. This, its only weakness, is one that will not have to be tested in most parts of India.

Sun's action on Dynamite.—A more important point in this country is the action upon it of sun-light and heat. Professor James Dewar experimented in midsummer upon dynamite in the following way :—Having placed some dynamite in an exhausted tube, it was heated for several hours on successive days by a current of steam, the tube being at the same time freely exposed to the action of light. This treatment gave no trace of any permanent gas or acid, and the substance showed no trace of any decomposition. At the same time it is very advisable that dynamite be never long exposed to the direct rays of the sun. At 158° Fahr. several grammes of nitro-glycerine will disappear from dynamite in a few days if exposed in thin layers in watch glasses. But from experiments on the Continent of Europe, in 5 years a sample of 1871 lost only 2·2 per cent., and in 4 years a sample of 1872 lost only

1·5 per cent. of its nitro-glycerine. Dynamite freely exposed to the air, however, must in course of years lose an important percentage of its active principle.

Dynamite how discovered.—Nitro-glycerine, discovered by a young Italian Chemist, Sobrero, at Paris in 1847, is formed by the action of nitric acid on glycerine—

$$\underset{\text{Nitric Acid.}}{3\,(HNO_3)} + \underset{\text{Glycerine.}}{C_3H_8O_3} = \underset{\text{Nitro-glycerine.}}{C_3H_5O_3\,3\,(NO_2)} + \underset{\text{Water.}}{3\,H_2O}$$

Concentrated sulphuric acid is added to remove the water formed, the heat evolved being artificially kept down to prevent the decomposition of the nitro-glycerine. Being only capable of partial explosion by ordinary methods, nitro-glycerine continued useless till the Swedish Engineer, Alfred Nobel, discovered the method of its complete and certain explosion by a detonator of fulminate of mercury. But the catastrophes resulting from its accidental explosion led to its abandonment. Nobel, however, in 1864 discovered that by mixing with the nitro-glycerine a porous infusorial siliceous earth, known in Germany as Kieselgurh (or any other absorbent substance), it not only retained its blasting powers, but that the readiness and certainty with which the nitro-glycerine exploded was somewhat favored by the mixture. Hence the introduction to the public of dynamite in 1867.

Two classes of Dynamite.—Dynamite is made of various strengths in two classes: one class in which the absorbent material is inert, serving only as a carrier for the oil; the other class which contains an active base—itself an explosive. Of these two classes the first is by far the most powerful, the second is little better than gunpowder. In the first class it is not only necessary that the mixture be complete, but that the oil be entirely absorbed, so that no separation can after mixture be possible either from movement in transport or from long storage. The complete admixture of its two ingredients is of great importance, and is effected by means of sieves and heating to 160° Fahr.

Characteristics of Dynamite.—All reliable dynamites possess the following characteristics :—

In appearance they are greasy and plastic like putty; when uncongealed, flesh colored, and when frozen, white; their density is 1·6, that of powder being 1·00; they burn quietly when exposed to a flame without producing any explosion, but when heated to 420° Fahr. they explode;

they can only be practically exploded by a cap or detonator, and when confined, the force of the explosion varies with the strength of the envelope; they are unaffected by exposure to damp, and in some kinds even by immersion in water; they freeze at a temperature 14° (Fahr.) warmer than the freezing point of water, and in this state are less readily exploded; their perfect explosion generates no noxious gases, though their burning does, but though the fumes are poisonous, habitual contact diminishes their hurtful effects; and, lastly, moderate shocks do not affect dynamite at all.

Dynamite Cartridges.—English dynamite has been manufactured under strict Government supervision since 1873 at Ardeer near Stevenston in Ayrshire by Nobels Explosives Company; Indian Agents, Messrs. Macaulay and Company, Bombay; Indian Instructor, Mr. John Harris. Nobel's Dynamite No. 1 is sold in cylindrical cartridges with a wrapper of parchment, which is thick, untearable, and impermeable to nitro-glycerine, though not to water, so that should the oil separate it cannot pass to the outside. These cartridges are consolidated by pressure, whereby any excess of nitro-glycerine, which the porous earth will not hold absorbed, is expelled. Each cartridge is $\frac{7}{8}$-inch in diameter, $3\frac{1}{2}$ inches long, and weighs 2 ounces: eight cartridges therefore go to the lb. The cartridges are made up in 5 lb. packages (with 37 cartridges and 9 primers, latter weighing each $\frac{3}{4}$ oz.) covered by a wrapper of oil skin which is waterproof, but not nitro-glycerine proof. Ten of these packages are packed in each wooden case, containing therefore 50 lbs. of dynamite. A ton of dynamite, like gunpowder, weighs 2,000 lbs.

Prices of Dynamite.—The prices of Nobel's Dynamite No. 1 with its appurtenances at any Indian Sea Port are as follows:—

	Prices. Rs.	As.	P.
Dynamite No. 1, per lb., ...	1	8	0
Treble Detonators, per box of 100, ...	2	2	0
Nippers for fastening detonators to fuze, each, ...	0	6	0
Improved nippers for ditto, each, ...	2	0	0
Gutta-percha (tape) safety fuze, (Bickford's) for blasting in wet places and for submarine work, per coil of 24 feet, ...	1	2	0
Red tape safety fuze, per coil of 24 feet,...	0	7	0
White tape fuze, " "	0	8	0
Electric fuzes 4½ feet long, each, ...	2	0	0

Large India-rubber lined bags for extra heavy blasts are supplied to order.

Detonating Caps.—In practice, dynamite is exploded by means of heavily charged percussion caps, of which *Fig.* 1 is a full size section.

The amount of charge in a detonating cap affords no indication of its strength, since it may vary in chemical composition. Some caps with a charge of 15 grains failed to explode a frozen primer, while other caps containing only 4½ grains succeeded.

This is caused by (i), impurity of the fulminate of mercury; (ii), the chlorate of potash with which it is mixed may be in excess; or (iii), the quantity of gum used to bind the charge and to protect it from moisture may be too great. The proper proportions in the fulminate giving the best results are:—

Fulminate of Mercury, ...	77·66 per cent.
Chlorate of Potash, ...	22·34 „
	100·00

To ensure the detonation of dynamite under all conditions, the detonator used must be capable of rupturing an iron plate ·03 inch thick when tied to it by a string. To illustrate the force of these detonators, it may be mentioned that a school boy at Halifax lost the fingers and thumb of his left hand by a detonator exploding in it. Two years previously a man had bought some detonators for exploding dynamite, but having no use for some of them, he soaked them in water to render them as he thought harmless, and threw them into the street, where one was picked up by the school boy, who seeing a white substance at the end of the tube, tried to extract it with a pin, when the detonator exploded.

Fuze fastened to detonator.—These detonating caps are laid in small tin boxes in sawdust; before using the caps, the sawdust must be blown out with a dry blow of the mouth: they must never be scraped. Bickford's fuze is used, cut to the requisite lengths with square ends, one of which is inserted in the cap until it touches the fulminate: the cap is then compressed with pincers near the open end, so as to bind and hold the fuze tightly.

Fig. 2 shows the detail, W being the compressed portion. *Fig.* 2A also further illustrates this.

Pliers used by wire workers are the most convenient, the cutting edges being first blunted: care must be taken that the pressure used is not too great, lest the fuze be separated from the fulminate, and the circulation of the flame be impeded. In wet or even damp places the junction is made water-tight with grease, white lead or tar smeared well over the whole portion of cap and fuze near W, *Fig.* 2.

Primers.—The fuze and cap being ready, a primer (weighing ⅜ oz.) is opened at one end, and the cap is gently pushed into the dynamite, so that a part of it is still visible; or if desired, a slender piece of box wood, termed a "regulator," with a shoulder to fix the depth up to which the cap can be inserted, is first pressed into the dynamite to form the hole for the receipt of the detonating cap. Care must be taken not to push the cap overhead into the primer, or the fuze will set it on fire and burn and waste the dynamite; or the flame of the fuze may ignite the dynamite, and the cap explode out of contact, when there would be no explosion of the dynamite. The cap inserted, the paper of the primer is then closed up, and bound round the fuze with a wire or piece of twine as shown in *Figs.* 3 and 3A, B being the binder.

The connection ought to be very securely made, so as to prevent the displacement of the cap.

Loading and Firing.—In making a blast, one cartridge is first placed in the bore hole and *pressed* or *squeezed*, *not rammed*, down with a *wooden*, *never an iron or metal*, rod in such a way that it forms a close contact with the sides of the rock: this process is repeated with a second, third or more cartridges according to the magnitude of the blast. Finally the primer, furnished with the cap and fuze, is lowered or pushed gently, but never rammed, into the bore hole until it rests on the charge. However heavy the charge may be, it is always advisable to employ a small exploding cartridge or primer. The space for about 8 inches above the charge is then gently filled with sand, clay or soil, and the rest of the tamping is formed of any more resisting material that may be at hand, gently packed with the wooden rammer. [Damp sand lightly packed forms an excellent tamping. Or water may be simply poured into the hole]. After this is done the fuze may be lighted. *See Fig.* 4.

When a blast has failed, the charge should not be withdrawn, unless water tamping has been used: such an operation would be attended with great danger. A fresh charge should be placed in a hole made near the former, and the explosion of this will generally insure that of the other; or about half the tamping may be removed, and a heavily capped cartridge introduced.

Frozen Dynamite.—Dynamite becomes frozen at 46° Fahr., but thaws slowly and resumes its pasty condition when warmed. Thoroughly congealed dynamite appears no longer flesh colored but white. To secure its full explosive effect, dynamite must be in the pasty state when used. It should not, as a rule, be applied in any way for blasting in a hard or frozen state. It is not dangerous when frozen, in which state it can be carried rather more safely than when unfrozen: but when frozen it can only be exploded with difficulty, and, by not fitting into the bore hole, it loses some of its explosive effect: it also thaws so slowly as to make the bringing it to a plastic condition a tedious matter: most of the accidents which have occurred in its use have arisen from attempts to thaw it quickly. Where circumstances do not readily admit of the charge of dynamite being thawed, the primer cartridge must at least be first thawed by placing it in the trowsers pocket: the primer thus used will explode the frozen dynamite.

It has been proved on a large scale that dynamite can be carried about, shaken, or even broken with impunity *when in a frozen state.* The following experiments among others, were made before Dr. James Thomson and Mr. J. T. Bottomley, Professor of Engineering and Lecturer on Science respectively, in the University of Glasgow. Several cartridges of dynamite in a frozen state were thrown, one by one, with great force against an iron plate: the cartridges were partly squeezed into lumps sticking to the plate, and partly were smashed to fragments which flew round about; but there was no explosion. A block of iron 400 lbs. weight was allowed to fall from a height of 20 feet on a light wooden box containing 20 lbs. of dynamite in a frozen state: the box was smashed, the cartridges crushed flat and pounded together, but no explosion. The crushed frozen cartridges were next made up into two heaps to be exploded. A small unfrozen cartridge or "primer" of dynamite, with detonator and fuze, was inserted in each frozen mass, and fixed successively, the two heaps of frozen dynamite being only a few yards apart. The explosion of the first, though very violent, did not set the other off. The second, however, made a very violent explosion when ignited by the unfrozen primer and detonator.

The freezing point of nitro-glycerine varies between 39° and 58° 6′ Fahr., owing to differences in manufacture. Samples from Nobel's factory at Zamky on the Continent, remained liquid under from 32° to 17° 6′

Fahr. Dr. Gladstone has noticed that nitro-glycerine when subjected to cold will become only thick or glutinous without freezing. Other experiments have shown that in nitro-glycerine exposed for several days to 50° and 32° Fahr. some crystals became detached and floated on the oil which did not congeal. Contact with silicious substances, such as silicious marl, hastens the freezing at temperatures below 53° Fahr. With dynamites composed of absorbent matters having a combustible tendency, the diminution in liability to explode was rather lessened when frozen. Soft silicious dynamite would not explode when fired at and struck with a bullet at 2,500 paces; at 2,000 combustion was produced. Frozen dynamite, however, would not explode even at 60 paces. The following are the results of trials by striking dynamite samples with a steel hammer:—

Unfrozen dynamite.					Dynamite between frozen and liquid.				
Fall	19·7	inches	.. ..	explosion.	Fall	19·7	inches	.. ..	explosion.
"	15·7	"	.. ..	"	"	15·7	"	.. ..	"
"	11·8	"	.. ..	"	"	11·8	"	.. ..	"
"	7·9	"	.. ..	"	"	7·9	"	.. ..	"
"	5·9	"	.. ..	"	"	5·9	"	.. ..	"
"	3·9	"	.. ..	no explosion.	"	3·9	"	.. ..	no explosion.
"	3·9	"	2 blows	"	"	3·9	"	2 blows,	explosion.
"	3·9	"	3 blows	"	"	2·0	"	.. ..	no explosion.
					"	2·0	"	2 blows,	explosion.
					"	1·6	"	.. ..	no explosion.
					"	1·6	"	2 blows	"
					"	1·6	"	3 blows	"

The sensibility of frozen nitro-glycerine to mechanical shocks is shown by the above experiments to be less than that of non-frozen nitro-glycerine, but in the transition state this sensibility is still further increased.

Frozen Dynamite how thawed.—To bring the dynamite from a frozen to a plastic condition, the most convenient arrangement is a double box, the inner one containing the cartridges, and the space outside it being packed with fresh manure. In this manner dynamite can always be preserved in a proper condition. In smaller quantities the apparatus shown in section in *Fig.* 5 is employed.

It consists of two concentric vessels, the inner one containing the cartridges, and the outer one hot, *not boiling*, water.

Blasting under water.—If the blast is made under water, it is absolutely necessary that water be prevented from touching the cap. A simple method has been already described. Another special arrangement is seen in *Figs.* 6 and 7. Here an outer envelope or zinc box is packed with grease and wax in the space W left above the top of the cartridge.

Velocity of Dynamite.—Groups of mines may be exploded simultaneously by joining them with dynamite trains about 1 inch thick, which are made of rubber or zinc tubes filled with the explosive. To insure success, it is necessary to place a heavily charged cap at the end of each train.

Mr. Abel has exploded a cartridge of dynamite weighing 2¾ ounces at one end of a wrought-iron tube 5 feet long and 1·22 inch internal diameter, by exploding a similar cartridge at the other end. The velocity of transmission along a continuous train of dynamite is about 20,000 feet per second; but it is reduced to 6,200 feet when the cylinders of dynamite are placed half an inch apart; and from various experiments it appears that the transmission of explosion from one charge of dynamite to a separate one varies with the distance between them, with the amount of the initial charge, and with the nature of the packing of the recipient charge.

Safety in transport and store.—Major Majendie, R.A., the Government Inspector of Nobel's English Factory, reports that: "Dynamite of the specified composition and quality is safer to transport than gunpowder packed in barrels." Some of the grounds for this assertion may be here given. Boxes filled with dynamite have been thrown from a great height with a great shock without exploding. They have been placed on an open fire when the dynamite burned slowly away without exploding. Dynamite has been in railway collisions, and, though the van and boxes containing it were smashed, no explosion took place. In Bombay, piece of iron weighing 250 lbs. was dropped 40 feet on a box of 50 lbs. of dynamite; box broken, dynamite scattered but not exploded. At Bombay one lb. of gunpowder scattered over 5 lbs. package of dynamite and exploded: no explosion of dynamite. Again, an iron plate was placed on 20 lbs. of powder, and on the plate 10 lbs. of dynamite: explosion of powder sent iron plate quarter of a mile into the air; fragments of parchment, with unexploded dynamite adhering, found lying on the ground. There are 14 dynamite factories in various parts of the world, and since the opening of the first factory in 1866, not a single accident has ever taken place with dynamite, either during carriage or storage. Experience has proved down to the present time that the danger of dynamite in its carriage by rail, ship, or cart becomes absolutely nil so long as the detonators by which it is exploded do not travel with it in the same carriage.

Dynamite how used.—Absolute instructions for the use of dynamite cannot be laid down any more than for the use of powder: everything depends on the nature of the rocks and the character of the work. Exactly parallel experiments are extremely difficult to obtain. Comparative experiments with explosives on masses of *concrete* would seem to promise fairer results than when tried on rocks, the homogeneity, nature and condition of which vary even in the same species of rock, and are next to impossible to predicate.

The following general principles, however, may be observed. The mode of proceeding is the same as for powder, only the holes should be further apart, of less depth and of smaller diameter, so as to obtain a more slender charge.

Bore holes for Dynamite.—The following are the diameters of the drills usually employed for different depths:—

						Diameter.
From 3 feet to 6 feet,	...	...	...	...	...	1 inch.
" 6 " 11 "	...	...	...	...	...	$1\frac{1}{2}$ to 2 inches.
" 11 " $15\frac{1}{2}$ "	...	...	...	...	...	2 to $2\frac{1}{2}$ "

The depth of the bore hole should be not less than equal to the length of the line of least resistance, and in no case should the bottom of the hole descend below the level of the face of the rock.

Calculations of charges.—When the rock is very compact, the length of the charge is made about $\frac{1}{4}$ the depth of the hole, in more favorable cases it may be $\frac{1}{3}$ or even $\frac{1}{8}$. The following formulæ may be employed in calculating the charges to be used.

$$W = \frac{C}{24} \cdot \overline{L.L.R.}^3 \text{ or } = \frac{C}{32} \cdot \overline{L.L.R.}^3 \text{ .... (1).}$$

Where W = the weight of the charge in lbs., Avoirdupois,

L.L.R. = Line of Least Resistance in feet,

and C a coefficient to be determined by experiment, according to the nature of the ground and the class of dynamite employed. In No. 1 dynamite the following values have served as data:—

Very solid masonry, ...	C = 0·33
Hard limestone, ...	C = 0·23
Soft limestone, ...	C = 0·15
Non-compact rock, ...	C = 0·12

Speaking generally of dynamite if—

E = the quantity of the dynamite charge in lbs., and L.L.R. as before,

then $E = C \cdot \overline{L.L.R.}^3$, where C = from ·003 to ·006,.........(2).

In framing estimates, it is generally reckoned that ½ lb. of dynamite is required for every 10 cubic feet of hard rock.

Dynamite how used in practice.—In soft grounds, clay, marl, &c., dynamite is employed in the following manner: a hole is made of 1 or 1·5 inches in diameter, and 8 or 12 feet in depth, one dynamite cartridge (2 oz.) is dropped to the bottom of this hole and exploded, when it forms a spheroidal chamber; this chamber is enlarged by means of other cartridges until it can hold 4½, 11, or 22 lbs. of dynamite, according to need, and it is then filled with the No. 3 explosive. The firing of a large charge of No. 3 dynamite should always be done by means of a cartridge of dynamite No. 1 furnished with a strong cap.

When it is desired to shatter a body by means of dynamite, it is first of all necessary to insure between the dynamite and that body a close connection, and also to multiply as much as possible the points of contact. The effect will always be greatly increased by placing on the opposite side of the substance to be shattered a resisting force, as for instance masses of stone or timber-struts.

Dynamite and powder compared.—In using dynamite, a deduction may be made as compared with powder as follows:—

	Per Cent.
For galleries in hard schist, ...	18
„ cuttings in syenite of medium hardness, ...	35
„ „ „ very hard, ...	48
„ „ granite,...	44

It may be assumed that hand labor is diminished from 40 to 50 per cent., which represents in time a diminution of one-half.

The following table, obtained from actual experiments, will show at a glance the relative values of gunpowder and dynamite.

Explosive.	Composition.	Heat evolved in explosion in Thermal units.	Volume of gas produced per lb of explosive in cubic feet.	Product indicating measure of blasting effect.
Gunpowder, ...	Potassium nitrate, 74·70 Sulphur, ... 12·45 Charcoal, ... 12·85 100·00	1,093	3·61	3,945
Dynamite No. 1,	Nitro-glycerine, ... 75 Silica, ... 25 100	1,780	8·56	15,236

Examples—I. Driving a railway tunnel under Clifton Downs, England, the bore holes being drilled by machinery of the same size and depth.

Explosives used.	Distance driven in yards forward	No. of bore holes or shots per yard forward.	Total No of bore holes.	Weights of explosives in lbs. for every 15 yards forward.	At per lb.	Cost of explosives.
Gunpowder, ...	8	31	465	1417½	d. 5	£ s. d. 29 10 7
Dynamite, ...	15	17	255	165	s. 2	16 10 0

II. In the Pribram mines on the Continent of Enrope, where dynamite is much used, there is a saving in using dynamite over gunpowder with electric blasting of 23 per cent. in the price per yard, 28 per cent. in wages, and 33 per cent. in time. When safety fuze and detonating caps were used, the corresponding figures were 9, 11 and 25 per cent. respectively.

Dynamite on Wood.—If it be required to shatter a piece of wood or a tree, by surrounding them simply with the cartridges, it will be necessary to employ the following charges of Dynamite No 1:—

Ounces.		In	In.		In.	
3·5	for a block of	4 × 4		or a tree of	4	in diameter.
8·75	„ „	8 × 8		„ „	8	„ „
35·00	„ „	12 × 12		„ „	12	„ „
105·00	„ „	16 × 16		„ „	16	„ „

A large saving in the charge will be made by drilling the substance for half its thickness, and filling the hole for one-half its length. Instead of having one hole, several can be made, converging in such a way that the whole of the charges explode simultaneously by the action of one cap. Then the following charges only will be necessary :—

3·5	ounces	for a diameter of		8	inches.
8·75	„		„	12	„
24·5	„		„	16	„

Examples—

I. In 13 minutes altogether, dead tree, 2½ feet diameter, 40 feet high, blown 2 feet into air and all roots dislodged with 1 lb. of dynamite.

II. With large tree (living), skin bark all round at root for 2 inches, encircle it with a half inch tube of dynamite, insert detonating cap and fuze, cover well with clay and explode. Tree will be severed at root with only 6 inches of wood destroyed.

Dynamite on Iron.—In order to break a rectangular piece of iron, the charge is placed on the wider side so as to occupy the whole of the width. This charge increases with the thickness in the following manner :—

For a width of 40 inches,

No. 1 Dynamite.	5·25 oz.	with the thickness,		...	·2	inch.
	1·32 lb.	„	„	...	·4	„
	5·28 lbs.	„	„	...	·75	„
	33·00 „	„	„	...	2·00	inches.
	132·00 „	„	„	...	4·00	„

Examples—

I. An ordinary double-headed iron rail can be cut by 8 ounces of dynamite placed against it (*Fig.* 8) and detonated.

II. Four ounces of dynamite with primer (⅜ oz.) sufficed to break cast-iron girder as shown (*Fig.* 9).

III. Hollow cast-iron road roller, 2 feet 10½ inches diameter and ¾-inch thick, weighing 473 lbs., smashed into 30 pieces with 8 ounces of dynamite.

IV. A cylindrical block of wrought-iron, 11½ inches diameter, 12½ inches long, and bored through the centre with a one inch hole, had its hole filled with 8 ounces of dynamite and exploded. One-half was blown 80 feet in one direction, the other half 50 feet in another, and stopped by banks. On examining the iron after explosion, the bore hole was found to be enlarged to $1\frac{3}{4}$ inch at the centre, tapering to the original diameter at 3 inches from the ends. The bore was not plugged. The explanation of the enlargement probably was that, the explosion, although practically instantaneous, commenced at one end where a portion of the charge was exposed to the resistance of the atmosphere only, its intensity gradually increasing as it neared the centre where it reached its maximum, and as gradually declining towards the other end of the bore which was open to the atmosphere. The area of metal thus torn was 120 square inches.

Dynamite on Walls.—To destroy a wall, the best method is to place the charge at the foot to a depth equal to half its thickness, and to pack the space above tightly with stones.

Examples.—I. 18 inch brick walls can be cut by $1\frac{1}{2}$ lbs. of dynamite per foot run placed against them without any tamping.

II. *Demolition of part of the Vienna Exhibition.*—The building was of stone concrete and had stood 4 years. In first experiment wall chosen was 2·3 feet thick, and 21 feet long. Along the foot of this wall was laid a charge of 55 lbs. of dynamite in rolls, or nearly 8 lbs. per running yard, and covered with 3 feet of earth. The effect of the blast was to bring down the wall, together with a portion of another standing 8 feet away with the arches resting upon the latter, and the débris was carried a distance of 200 paces: the charge therefore appeared excessive. In the second experiment the charge was reduced to less than one-half, the effect being the complete destruction of the wall. In the third experiment the charge was again reduced from 26 lbs. to 18 lbs., which proved amply sufficient. Taking the last charge and substituting in the formula

$$L = mw^2, \qquad (3).$$

Wherein L = charge in lbs. per lineal foot,
m = coefficient to be found by experiment,
w = thickness of wall in feet,

we obtain,

$$\cdot 86 = m \cdot \overline{2{\cdot}3}^2 = m \times 5{\cdot}29$$

$$\text{Therefore } m \text{ (the coefficient required)} = \frac{\cdot 86}{5{\cdot}29} = \cdot 162$$

$$= \frac{1}{6} \text{ nearly.}$$

Dynamite on Rock.—*Examples*—

I. The St. John Del Rey Silver Mining Company used dynamite, and found it more effective and economical than gunpowder. Formerly the Company made its own powder and thus saved freight, duty, and inland carriage of one of its component parts, charcoal. Now they send out the dynamite at a greater first cost, and pay the freight, duty and carriage on the whole bulk, yet have saved £2,000 a year by its use. As regards its transport, the Company had no difficulty in obtaining ships to carry it at the same freight of gunpowder, or in inland 300 miles by rail as far as the railroad goes, then by waggons, and lastly on mules backs, and without a single accident during the seven years the Company has used it.

II. Large piece of hard gneissic rock $3\frac{1}{2}' \times 2' \times 2'$ shattered to bits by 8 ounces of dynamite placed on top and covered with clay, and exploded with fuze and detonator.

Dynamite in earth is not so effective as gunpowder.

Dynamite on rock under water.—*Examples*—

At the Lydney Harbour Works, England, in 1873, both gunpowder and dynamite were tried. The following were the objections to powder :—

(i). It was requisite to bore 18 inches below the required depth in order to effect the displacement of the rock.

(ii). The rock when broken came away in large pieces difficult to lay hold of with the dredger.

(iii). The miss-fires amounted to 15 per cent., and a miss-fire always involved moving the raft from which the holes were bore slightly, and of boring another hole near the unexploded one.

(iv). The process was slow.

The advantages in using dynamite were—(i), it was not necessary to bore the holes so deep; (ii), very little tamping was required, the 12 feet head of water being nearly sufficient of itself; (iii), the explosion was sharper and more radiating, shattering the rock, instead of breaking it into large pieces, thus enabling the dredger to pick it up with ease; (iv), there were no miss-fires, and (v), the process was quick.

The relative cost of removing 10 cubic yards of rock and placing it on shore was—

	With Gunpowder			With Dynamite.		
	£	s.	d.	£	s.	d.
Drilling holes, ...	0	11	3	0	7	6
Powder cartridges with fuze, ...	1	0	0		...	
Dynamite with detonators and wire, ...		...		0	13	11
Miss-fires, 15 per cent.,...	0	4	8		...	
Dredging 10 cubic yards, ...	0	15	0	0	15	0
Interest on dredger and plant, &c., ...	0	3	4	0	3	4
	2	14	3	1	19	9
	or 5s. 6d. per cubic yard.			or 4s. per cubic yard.		

Dynamite on river obstructions.—*Examples—*

Blasting old piles, snags, &c., in Danube near Vienna.

I. Two heavy 18 inch piles of old bridge, 15 feet apart, 100 feet from centre line of existing bridge, and 400 feet from left bank, mean depth of water round them 10 feet, their heads just above mean water level, current very violent, and bed of river washed out 5 feet deep on down-stream side. Cartridge with 2·2 lbs. of dynamite made up with primer and wires in tin case, case coated with gutta-percha composition, wires being allowed to project, and secured to long wooden pole which was pushed down on the up-stream side of the pile close to the ground and fastened to the pile. Wires were also covered with gutta-percha. The electric battery was on shore. On explosion, column of water sent up 25 feet into the air, and both piles broken off flush with the ground.

II. Two heavy oak logs were found embedded in the Danube Canal, first 25 feet long with large roots, and mean thickness of 5 feet, it was lying crosswise deeply imbedded in the gravelly bed, and as usual there was a deep hole on the down-stream side and a bank up-stream. Depth of water over log 5 feet. Two tin cases filled with 13 lbs. of dynamite as before; these cases were attached to lower ends of 2 poles, which were driven into the ground on up-stream side of oak log, and 6 feet from each end: the tin cartridge cases were thus brought into close contact with the log, and were about 13 feet apart. Firing as before. But explosion much more violent, water, gravel and débris being thrown up 33 feet. From soundings immediately taken, it was found that, not only had the logs been completely destroyed and removed, but that the bed of the Canal had been equalized, the depth of the water being now 10 feet throughout. Second log, 7 feet long and 3 feet 4 inches diameter; depth of water over root 4 feet. Dynamite charge 8 lbs. Destruction immediate and entire. Both the logs removed in 3½ hours at a trifling cost.

Experiments with Dynamite.

To—The Supdg. Engineer, 2nd Circle, Coimbatore.

Dated Ootacamund, 6th July 1880.

Order to conduct experiments.—With reference to Public Works G. O. No. 2686W., dated 24th October, 1879, I have the honor to submit my Report with Plans and Tables of the results of a "careful series of experiments made to elucidate the best method of employing dynamite and its economical value as compared with gunpowder in all the ordinary operations of the Department, *e. g.*, removing rock with good or bad faces in the constructions of ghaut roads, breaking up and removal of boulders from road surfaces or elsewhere, 'getting' rock for the manufacture of road metal, &c."

Experiments how carried out.—The experiments, to be reliable, required considerable intelligence in the person prosecuting them, and very accurate plans and sections of the demolished rocks both before and after the explosion. For this purpose I placed Sub-Engineer and Conductor Mr. A. Milne in charge of the experiments, and gave him full and detailed written instructions as to the manner in which they were to be carried out, and the points of enquiry to which his attention was to be directed. Mr. Milne came to me from the Wynaad, and was at Metapolliem from January till April doing nothing else but carrying out these experiments. I visited him eight times, and Mr. John Harris, Indian Mining Instructor of Nobel's Explosives Company, visited him twice, remaining with him several days each time. Colonel Sankey, C.B., and yourself also kindly witnessed some of the experiments in April last. Specimens of all the rocks experimented upon were sent to Surgeon

Major George Bidie, M.B., F.L.S., of the Madras Museum, to be classified and described; and their specific gravities were also accurately ascertained. A careful record has also been kept of the cost of boring and of removing the exploded rocks. No effort has in short been spared to obtain, by measured sketches made on the spot, by plans, sections and figured records, the actual facts. Nothing has been left to guessing or even to approximation. The dynamite used was Nobel's No. 1. The powder was obtained from the Government Factory at Madras, and is well known as being the very best of its kind, peculiarly well suited for blasting rocks. The jumpers used for boring were each 1, 1¼ and 1½ inches in diameter.

Extent of experiments.—To show the extent of the experiments, I may note that eight different descriptions of rock were demolished,† 500 lbs. of dynamite, 100 lbs. of gunpowder, and 800 running yards of fuze were used, 1,200 bore holes, requiring 1,000 lineal yards of boring, were made, and 4,300 tons of rock were operated upon, at a total cost of Rs. 4,082.

Experiments how recorded.—The experiments on dynamite recently conducted near Metapolliem are all recorded in the accompanying twenty-two plans and in the Record Book.* The plans and sections are drawn to a scale of 4 feet to the inch, or $\frac{1}{48}$. The sections are not distorted, the horizontal and vertical scales being the same, and the entries in the Record Book are numbered consecutively for easier reference. Nearly all the experiments have been abstracted into the Tabular Statement No. I., which is attached to this Report, and which contains all the results arrived at under every heading and in every form that was thought likely to be of use. This Table I trust needs no explanation, but speaks for itself.

* *Editor's Note.*—The Author sent the Record Book of the 1180 charges for publication, but as that was too voluminous, a short Note seems necessary. Table No. I. is Author's abstract of the Record Book, and the first five columns have been added here to show clearly the number and nature of the charges fired, from which the totals in the abstracts have been deduced. It will be seen that the great majority of the charges are small, they were all apparently in vertical bore holes, and in the case of the larger charges, the dynamite filled up two-thirds of the bore holes, so that the line of least resistance was greater than the tamping. The specimen plan published shows the nature of the faces operated on. The bore holes were slightly

† All these remarks appear to apply to "demolition of" not "getting" rock for building purposes, see page 35.—[Ed].

in excess length of the line of least resistance. The dynamite experiments recorded in Table I. were 884 : from 885 to 1036, or 152, were charges of gunpowder for sake of comparison, shown as cases No. 21 and 22 in Table I.; and from 1037 to 1180, or 144, were dynamite charges on detached rocks or boulders, of which the results are abstracted in Table II.

Dynamite and gunpowder compared.—Taking the experiments altogether, we obtain the following results with dynamite and with gunpowder :—

	With Dynamite.		With Gunpowder.
Weight of explosive used per ton of rock blasted,	0·13	lbs.	0·4
Lineal feet of holes bored " " "	0·84	feet	1·96
Number of men moving rock " " "	0·48	men	0·9
Lineal feet of fuze used " " "	0·70	feet	1·56

The proportion of weight of rock loosened to the weight of explosive employed is—

In Dynamite, ...	18,488 to 1
In Gunpowder, ...	5,464 to 1

Rankine says in gunpowder from 7,000 to 14,000 to 1 in small blasts, and from 4,500 to 13,000 to 1 in great blasts. But he probably refers to sedimentary rocks and easy rocks like chalk as well as to granites, &c. Rankine also states that in gunpowder from $\frac{1}{2}$ to $\frac{1}{4}$ of a ℔. of powder is generally required for each ton of rock removed; our powder experiments give 6·7 oz., or $\frac{2}{5}$ of a ℔. per ton. In dynamite we see that $\frac{1}{8}$ of a ℔. sufficed: and in No. 644 of the experiment books, the charge was only $\frac{1}{16}$ of a ℔. per ton. Hurst gives 3 ℔s. of powder to every 100 cubic feet of rock blasted: our experiments in dynamite give 1 ℔. of dynamite for the same.

In the Metapolliem experiments, No. 14 of dynamite and No. 21 of gunpowder in Table No. I. are the most similar and comparable. From these two experiments we learn that, by using gunpowder and dynamite, the following relative proportions resulted in producing equal effects, the price of powder being 10 annas, and that of dynamite Rs. 1-8 per ℔.:—

	Gun-powder	to	Dyna-mite.
Explosive charge in weight per ton of rock removed, ...	1	:	0·5
Bore holes " " " " ...	1	:	0·3
Labor for removing rock after blasting " ...	1	:	0·6
Fuze " " " " ...	1	:	0·5
Entire cost " " " " ...	1	:	0·7
Time " " " " ...	1	:	0·5

Or, in other words, to produce the same effect on a mass of rock, dynamite requires only one-half the quantity of the explosive and of the fuze, one-third the number of bore holes, three-fifths of the labor for removing the rock after blasting, that powder does; at a saving of three-tenths in the entire cost, notwithstanding the price of dynamite being 2½ times the price of powder; and it enables its work to be done in one-half the time.

In blasting, dynamite shatters the rock much more completely than powder does: powder tears it out in bulky masses; dynamite in slaty slices or splinters. The effect of the explosive force of dynamite also frequently extends very far beyond the seat of the charge, thus assisting succeeding blasts, (*see* No. 1118 of the Record Book.) Dynamite does not generally throw the rock out so far as powder, but it cracks and splits it into more numerous and thinner portions than powder does, thus lightening the labor of disentangling the pieces; and it leaves the rock generally so disintegrated, and with such sharp angles, as to greatly facilitate its after removal with the sledge hammer and crowbar. This is illustrated by the following figures which were obtained from the experiments at Metapolliem:—

		Dynamite.	*Gun-powder.*
In every 100 cubic feet of rock blasted.	Rocks shattered by the dynamite and loosened by the powder, ...	78	56
	Rock thrown out a moderate distance, ...	21	43
	Rock thrown out a considerable distance,	1	1
		100	100

and

In every 100 cubic feet of rock disturbed by the first blasts.	Rock which had to be re-blasted,... ...	5	20
	Rock removable by hand, ...	62	20
	Rock removable by crowbars, ...	33	60
		100	100

The peculiar *percussive* effect of dynamite is well illustrated in No. 1114 of the Record Book, where the upper portion A was knocked off as it might have been by a hammer.

Dynamite does not act in the line of least resistance as powder does; its bore holes can, therefore, be made shallower and further apart than those required by powder.

Dynamite how best employed.—Regarding the best methods of employing dynamite, the experiments show that the bore holes should not, as a rule, be more than 5 feet deep. Dynamite used in deeper holes loosens larger rocks, which generally have to be re-bored and blasted, unless they are situated at a height and are blown by the explosion across the roadway which it may be intended to open to traffic: in road-making, however, it is often economical to retain stone not immediately wanted, but which subsequently is used up in culverts and walls.

The depth of the bore holes should, as a rule, be *equal to* the length of the line of least resistance, and their distances apart from 1½ to 2 times their depth. Exceptions may arise, as in section, *Fig.* 10, *Plate* II., where if the piece ACB had to be removed, and BC = *d* 4, and AC = *d* 6 feet, then a 6 feet hole should be bored, and exploded with a charge for a 4 feet line of least resistance.

Cracks and fissures in the rock blasted are of great importance, and should be studied in order to enable the blaster to decide on the position of the bore holes. *The charge of dynamite should always be laid in a sound piece of rock,* not nearer to a crack if practicable than one foot. The plan and section, *Figs.* 11, 12, *Plate* II., will illustrate this point. The lines in both show the cracks and cleavage in the rocks. The best position for the bore hole to contain the charge of dynamite is A. At B or C the charge would have to be doubled, or even quadrupled, and then the effect might be comparatively feeble. If the cracks between the face of the rock and A (the back) are open, leaving cavities, the effect of an explosion of dynamite in the bore hole at A would remove less rock than if the rock were quite sound: but, if the cracks are very close, as is not seldom the case, then the results of the explosion will be better than in perfectly sound rock.

In using dynamite a large number of bore holes placed in a group, or laid in line, if not further apart than 9 inches, can all be exploded almost simultaneously by the direct ignition of only one of the charges, *see* Nos. 1113, 1114, 1109, 1108, 1060, 1061, 1062, 644, in the Record Book.

When it is desired to shatter rocks by means of dynamite, it is absolutely essential *to insure between the dynamite and the rocks operated on a close connection, and also to multiply as much as possible the points of contact.* These are conditions of the first importance, and should always be borne in mind when using dynamite. For this reason several bore holes of moderate diameters are preferable to one hole of a larger diameter, no account being taken of the greater convenience and often of economy also in working a smaller jumper. To illustrate this point, let us take four holes of any length, each one inch in diameter, and each loaded to a depth of 4 inches. There will thus be in all a length of 16 inches of bore hole, loaded altogether with 11·72 ounces of dynamite. To hold that quantity of dynamite, a two inch hole must be filled to a depth of 4·37 inches. Now in the case of the four one-inch holes, each loaded 4 inches deep, the square surface of contact between the dynamite and the rock will be 50·27 square inches. Whereas in the case of the one two-inch hole loaded with the same quantity of dynamite to a depth of 4·37 inches, the surface of contact will be only 27·45 square inches, or little more than one-half the surface in the former case. It is thus clear that, speaking generally, a number of bore holes moderately small are preferable to a single hole of a larger diameter.

In the case of a gently sloping rock with no face, dynamite should be used very much as powder is in such a case, only with shallower and fewer bore holes. As the line of least resistance is not so important in dynamite as in powder, the necessity for sloping the holes is not so great. Nos. 1157 to 1173 of the Record Book show how faces can be formed on sheet rock with gentle slopes. But, if a face be required on a flat rock, sloping holes must be resorted to. Attempts to form a face by numerous shallow holes with small charges, and by deep holes near together with heavy charges failed. *See* Nos. 1150 to 1156, 1144 to 1147, 1124 to 1132, 1119, 1120, of the Record Book which illustrate this point.

Where a well may have to be sunk through rock, a face may be obtained by drilling three holes, 9 inches apart, in the form of an equilateral triangle, and not more than 4 feet deep, and loading each of them with heavy charges of dynamite. The firing of any one charge will explode the other two. *See* Nos. 1037 to 1069 inclusive of Record Book for rock blasting in a well; and Nos. 1053 to 1056, 1060 to 1062, and 1067 to 1069 to illustrate the method of blasting several holes together. This method of firing may also sometimes be adopted with advantage in breaking up very large boulders.

Dynamite in "getting" road-metal.—Owing to the shattering and splitting effect of dynamite on rock, this explosive is peculiarly well fitted for affording assistance in obtaining road metal. The rock, whether in the solid or in boulders, is first blasted in the usual manner, and then such pieces as are too big to be sledge-hammered are bored with fresh holes, one-third the vertical height of the blocks in depth, and charged with one ounce of dynamite to every 4 square feet of least vertical section. The rock is thus shattered into pieces, small enough to be readily broken into road metal. All rock on which dynamite is used as an explosive becomes so disintegrated, as to make the obtaining from it of road metal a very easy and cheap process. The saving in cost is 40 per cent.

Hasty demolitions with Dynamite.—*Hasty demolition of rocks.* Dynamite, unlike gunpowder, enables this to be done by the mere superposition of the explosive on the rock to be broken without using any bore hole. This method answers but feebly on solid gently sloping sheet rocks with no face. In such cases this method cannot be advocated; it is both cheaper and quicker to bore holes. Examples of obtaining a face on sloping rocks will be found in Nos. 1149, 1157 and 1172 of the Record Book. But, where boulders or partly decomposed fissured rocks have to be very rapidly removed, the dynamite can be merely laid on the surface of the rock without any bore hole, covered up and exploded with the desired effect. The only objection to this method is that a much larger quantity of the explosive must be used than if a hole or two, however shallow, be first bored and filled with the dynamite and then exploded. In fact it can only be justified where time is of much greater importance than a wasteful expenditure of the explosive. *See* Nos. 1086, 1087, 1088 and 1089 of the Record Book.

If an hour or two can be secured, the best plan is to bore close together several shallow holes (made as deep as the time allows), to fill them with dynamite, connect the charges with other cartridges of dynamite pressed close against the rock, to fix the primer, detonators and fuze in the centre of all the holes, to cover up with moist clay, flat heavy stones, &c., and to fire the charge. The depth of the bore holes, if there be time, should be about one-fifth the vertical height of the rock or boulder, and about 3 feet apart according to circumstances. The charges should be calculated at one ounce to every square foot of vertical section. *See* Nos. 1108, 1109, 1113 and 1114 of the Record Book.

Holes of various shapes (oblong, square, crosswise) were chiselled into the surface of large boulders, filled with dynamite, covered with clay and exploded. But the results they gave were not so good as with inch bore holes four times deeper than the rectangular holes : chiselling the rock is more expensive and takes a longer time than boring, while the explosive effect is not increased. *See* Nos. 1115 and 1116, and compare them with Nos. 1108 and 1113 of the Record Book.

Where time does not admit of any holes being made, the rock should be first carefully examined to discover some crevice or hollow place near its centre in which the dynamite can be laid. This spot should be first washed clean of all dirt, dust and rock débris, the dynamite should be removed from its parchment wrapper, and be pressed down with the fingers, protected by a glove, into the seat of the charge, advantage being taken of any weak lines in the rock, along which it should be laid. The charge should not be heaped up higher than the depth of two cartridges (2 inches). The primer, detonator and fuze being inserted, the whole charge should be well covered up to as great a depth as possible with moist clay, earth, flat heavy stones, &c., and then exploded.

From numerous experiments it was found that two ounces of dynamite to every square foot of least vertical section sufficed to break up boulders of gneiss rock in this way. The manner of laying the dynamite on the rock, and the nature of the rock itself of course affect this proportion. If, for example, the rock is firm, but has a tendency to break up into regular solids, as quartz and trap often do, or if a hole in the rock favors the placing of the charge, then the dynamite may be reduced.

But circumstances may necessitate the dynamite being exploded on the rock without any covering at all. In this case it must also be applied exactly as above described, but the charge must be increased to 3 or 4 ounces per square foot of least vertical section.

Dynamite on Field Service.—*Hasty demolition of gates, &c.* The explosion of dynamite is almost instantaneous, and to a certain extent and under certain conditions so local, that, when not confined, its effect, though extraordinarily severe, acts only on one single part of the object against which it is placed. This feature of dynamite is well illustrated by an experiment made by Mr. John Harris at Beypore. Two vertical hollow cast iron columns (supporting the beam of an engine), each one inch thick, 9 inches in diameter, and 4 feet apart, were experimented on with dynamite in the following way:—1½ lbs. of dynamite was tied to one side of each column in a bunch, and these two charges were connected by a chain of dynamite cartridges and exploded. Four holes, two in each, were simply knocked through the two hollow columns according to *Figs.* 13 and 14, *Plate* II. just as if a cannon ball had passed completely through both of them, but otherwise the columns were absolutely uninjured and remained standing unmoved. Thus a 5 lb. packet of dynamite laid against the gate of a fortress and exploded would simply knock out a curvilineal hole about 2 or 3 feet square. But if the same quantity of dynamite was laid against the middle of the gate in flat bags, say of tin or cloth, so that the thickness of the charge did not exceed one inch, the gate would probably be shattered from top to bottom.

Dynamite tamping.—Different materials were tried in tamping the bore holes with the following results:—

Clay was found to be the best material for tamping in all sized holes. It was used quite dry and in a fine powder. The first 6 inches of the tamping next the charge were gently pressed with a wooden rod, and the remainder was poured into the bore hole with the hand in a small stream and sharply punned with the rod.

Sand was used in tamping the bore holes in precisely the same way as clay was used. With deep holes it was not found to be inferior, but in smaller holes it was decidedly inferior to clay, and in very small holes (about a foot deep) it appeared to have no effect at all.

Water as tamping appeared to be as good as any other in small bore holes up to about 2 feet, but in deeper holes it was inferior to clay and sand. Water is very convenient in miss-fires, as the fuze and primer can be easily removed, and a fresh fuze and primer re-inserted. But miss-fires occur so seldom when Bickford's fuze is employed, that this advantage is hardly felt. During the whole of our experiments there was only one miss-fire. Water tamping, moreover, is more expensive, and takes up more time than dry tamping: the fuze used with water tamping costs double the ordinary fuze; and after the detonator is secured to the fuze the junction must be made watertight with grease or wax. It cannot be used in holes that are cracked. Water tamping should only be used in wet places, or when the explosion is effected by an electric battery. When a battery is used a miss-fire is more likely to occur than when Bickford's fuze is employed, and thus water tamping allows of the fuze being easily removed and a fresh one being put in.

When no tamping was used the results were scarcely inferior to those obtained with tamping. When the holes are very shallow (9 inches to 12 inches deep) tamping is unnecessary.

On the whole it matters little whether clay, fine sand, or dust (such as worn down road materials) is used for tamping: at all events it is not necessary to go to much trouble to procure clay.

Speaking generally, the tamping is a weak point in shallow holes. In holes of 1 and 1½ inch diameter, a depth of 2½ feet of tamping is quite sufficient. A greater depth of tamping does not augment the effective power of the explosive, while a less depth caused a loss of power through the bore hole.

Miss-fires.—When a miss-fire occurs with water tamping, it is only necessary to remove the fuze and primer from the hole and put in a fresh one, but when any stiff tamping is employed, in case of a miss-fire, the tamping must on no account be removed; this would involve great danger. A fresh hole must be bored not nearer than 6 inches to the old one, and be loaded and exploded in the ordinary way. The explosion of the charge in the new hole will most likely explode the first charge. But should the first hole be one of considerable depth, it will only be necessary to make the new hole 6 inches lower than the top of the charge of dynamite in the old hole.

Where the rock is vertically stratified, or is likely to crack in one direction more than in another, the new hole should be bored on this weakest line. In the sketch plan (*Fig.* 15, *Plate* II.) the lines show the direction in which the rock most readily splits. C is then the proper position for the new bore hole with respect to A the old hole. If C were bored at D, the chances of its exploding A would be considerably diminished.

Explosive charges of Dynamite.—*Formula for calculating charges of dynamite.*—In Treatises on rock blasting, the usual direction is that the charge should vary with the line of least resistance $\overline{L.L.R.}^3$, or in other words with the rough contents of the mass of rock to be blasted. But where the charges and the lines of least resistance are comparatively small, this rule does not hold good, at least so far as dynamite is concerned, and probably in the case of gunpowder also. We discovered this fact in this way. We took, say, a 3 feet line of least resistance, and loaded numerous corresponding bore holes with various charges until one was found which exactly answered. With the co-efficient on the $\overline{L.L.R.}^3$ thus obtained, we calculated other charges for holes with lines of least resistance both less and greater that 3 feet. We always found that where the lines of least resistance were less than

3 feet, the charges thus calculated were too low, while with lines of least resistance greater than 3 feet they were too high. From these results, which were tested over and over again, it seems clear that the explosive charges, or, which is the same thing, the resistances to the charges do not vary as the $\overline{\text{L.L.R.}}^3$, or as the mass of rock operated upon taken alone. An investigation of the problem seems to show that the square surfaces of the rock from which the mass is torn $\overline{\text{L.L.R.}}^2$ should also be considered, and that these affect the result much more than the mass.

I will now endeavour to solve this problem.

Let us take the most common case of rock blasting with two clear faces, and assume the depth of the bore hole to be $1\frac{1}{4}$ times the line of least resistance, or L.L.R., and that the rock will fracture evenly on the three surfaces DE, FG, GH, (plan and section, *Figs.* 16 and 17, *Plate* II.,) shown by the dotted lines. The explosive will therefore *fracture* the rock on these three surfaces, and also push along the mass C on DE, *i.e.*, overcome the *friction* of the mass C on DE, (see section, *Fig.* 17). To put this into a formula, let us call the whole explosive Force P, the fracturing Force R^s, and the Frictional Force R^f,

Then $$P = R^s + R^f, \quad \text{.......(1)}.$$

Applying this formula to the above figures we find—

$$R^s = 6{\cdot}5 \times \overset{\text{Area of 3 surfaces}}{\overline{\text{L.L.R.}}^2} \times r, \quad \text{.......(2)},$$

where r is the resistance offered by one square foot, and

$$R^f = W \times \cos 35^\circ \text{ (angle of friction)}$$

$$= \overset{\text{Mass C.}}{2 \times 1 \times 1\tfrac{1}{4}\, \overline{\text{L.L.R.}}^3\, w} \times {\cdot}82$$

$$= 2{\cdot}5 \text{ nearly } \overline{\text{L.L.R.}}^3 \times w, \quad \text{.......(3)},$$

where w is the weight of one cubic foot of the rock blasted.

Substituting (2) and (3) in (1)

$$P = 6{\cdot}5\, \overline{\text{L.L.R.}}^2 \,.\, r + 2{\cdot}5\, \overline{\text{L.L.R.}}^3 \,.\, w$$

or $$P = 2{\cdot}5\, \overline{\text{L.L.R.}}^2 \times \{2{\cdot}6 \times r + (\text{L.L.R.})\, w\}, \quad \text{.......(4)},$$

and the formula will take this form wherever the direction of the fractures may be, and whatever angle of friction may be assumed.

Taking $w = 180$ lbs. Avoirdupois,

and $r = 432{,}000$ lbs. Avoirdupois,

and substituting

$$P = 2\cdot5\ \overline{L.L.R.}^2 \times \{\underset{\text{Tearing Force}}{2\cdot6\,(432{,}000)} + \underset{\text{Frictional Force}}{180\,(L.L.R.)}\}$$

or $$P = 540\ \overline{L.L.R.}^2 \times \{6240 + (L.L.R.)\}, \text{.................} (5).$$

Now the explosive charge is obviously proportional to the disruptive force P.

Taking therefore L.L.R. from 1 to 10 feet, and omitting the common factor 540 $\overline{L.L.R.}^2$ from equation (5), we obtain

	L.L.R. feet.		Tearing Force due to area,		Frictional Force due to contents,		Tearing Force due to area.		Frictional Force due to contents.
Charge for	1	varies as	6240	+	1,	or as	1	+	·0016
"	2	"	6240	+	2,	"	1	+	·0032
"	3	"	6240	+	3,	"	1	+	·0048
"	4	"	6240	+	4,	"	1	+	·0064
..	..	..	&c.	..	&c.	..	..	..	..
and charge for	10	"	6240	+	10,	"	1	+	·016
" "	100	"	6240	+	100,	"	1	+	·16

thus agreeing with what was discovered experimentally, viz., that the area offers the greatest proportionate resistance in small, while the mass does so in large, blasts. It is not for a moment supposed that the above figures are absolutely correct, or that they give the correct proportions of the influence on the charge of the forces due to area $\overline{L.L.R.}^2$ and to contents $\overline{L.L.R.}^3$ But it is believed that they accurately indicate, in calculating the required explosive charge, the preponderating influence of the former element.

That the area may the most affect one problem while the contents affects another is shown by the following case.

A boulder quite free at the bottom with a *vertical* bore hole down its centre can only resist fracture by means of its *cohesion*, and here the charge to explode it must vary as the area $\overline{L.L.R.}^2$ But if the bore hole were drilled *horizontally* into the boulder, then the charge might be affected more by the *weight* $\overline{L.L.R.}^3$ than by the area, and if the mass is very large, the resistance due to the weight or $\overline{L.L.R.}^3$ would greatly preponderate.

Or we may take a case in which the contents of the rock facilitates the blasting of it, and acts inversely on the calculation for the explosive charge. *For example*, (*Fig.* 18, *Plate* II.) supposing AE to be a piece of rock projecting from the main mass AH, and that CE is required to be blasted off; the requisite charge would here be obviously less than if DE were supported, because CE would by its weight $\overline{L.L.R.}^3$ assist the explosive in fracturing the rock at CG. Again, if the piece to be blasted extended to F (FBEK), then the explosive charge required would be less than that necessary for only CBEG, because the mass assisting the fracture would be greater, while the sectional area remained very much the same. And in the example given in *Fig.* 18, *Plate* II., the explosive charge diminishes until a point is reached (say at DM) when the weight of the mass ME causes a rupture at MD by its own weight alone without any explosive.

With the above considerations, in calculating explosive charges of dynamite for rock under various conditions, the equation ought, therefore, to assume the following form :—

$$W = A\,\overline{L.L.R.}^2\,B + \overline{L.L.R.,}^3 \text{ ....(6)},$$

W being the weight of the charge in ounces Avoirdupois, and A and B co-efficients to be determined by experiment.

In a case like that shown in *Fig.* 18, the equation would take this form,

$$W = A\,\overline{L.L.R.}^2 - B\,\overline{L.L.R.,}^3 \text{ ....(7)},$$

but this is not at all common in practice.

We have taken formula (6), and by numerous direct experiments have applied it to four common cases of rock blasting usually met with in practice. The values of the co-efficients A and B have been found by experiment on the gneiss rocks which were blasted near Metapolliem; and the results have been embodied in Table II. In other kinds of rocks a few experimental trials must be first made, and a similar table can then be constructed for them.

At the end of Table II. will be found explosive charges for gneiss boulders exploded with deep and shallow bore holes, with no holes at all, and with dynamite laid upon them with no covering. Table II. has been tested over and over again during the experiments at Metapolliem, and is believed to be very accurate.

Of course in practice the simple conditions, to meet which the charges in Table II. have been calculated, are seldom exactly met with. The rocks generally present a combination of those conditions. In such cases the charges must be taken as a mean between the given conditions; and judgment must be exercised. No more exact a Table is possible. Moreover, it is seldom that, in any charge, less than a cartridge or than a primer is used. A cartridge weighs 2 or 2½ ounces, and a primer ¾ of an ounce. Thus where in the Table a charge of 19·4 ounces is entered, 20 ounces, or 9 or 10 cartridges, would of course be put into the hole: or where 0·4 ounces is entered, a primer ·67 ounce would be used. A Table to suit the cartridges might be formed in this way. Taking the commonest case of one clear face and the two sized cartridges supplied, we obtain the following:—

Line of Least Resistance in feet.	Explosive charges in ounces Avoirdupois.	Number of Dynamite Cartridges. No. of cartridges 8 to the lb. 2 ozs. = 1 cartridge.	No. of cartridges 7 to the lb. 2¼ ozs. = 1 cartridge.
Lineal feet.	Ounces.	No. of Cartridges.	No. of Cartridges.
1	¾	Primer.	Primer.
1½	1½	2 Primers.	2 Primers.
2	3	1 Cartridge + Primer.	1C + P
2½	5¼	3 Cartridges + P.	2 + P
3	8¾	4 + P	3 + P
3½	12¼	6 + P	5 + P
4	17½	9 + P	8 + P
4½	23¾	12 + P	10 + P
5	31½	16 + P	14 + P
5½	40½	20 + P	17 + P
6	51	25 + P	22 + P
6½	63½	32 + P	28 + P
7	78	39 + P	34 + P
7½	94	47 + P	40 + P
8	112	56 + P	48 + P
8½	133	67 + P	57 + P
9	156	78 + P	67 + P

In Table II. two columns have been provided, one giving the explosive charge in decimals of a lb., and the other the fraction of the $\overline{L.L.R.}^3$ resulting from that charge. It will be seen that in shallow bore holes the fraction is much larger than in deeper holes. To compare these charges with those of gunpowder as recorded in various works of reference, I may here add that—Colonel Schun, R.E., in Ceylon, blasted cracked gneiss with gunpowder, using small holes 18 inches deep, and his charges were *in lbs.*

$$\frac{\overline{L.L.R.}^3}{6} \ldots\ldots\ldots\ldots (8).$$

In closely packed limestone near Attock, with powder made by the officer in charge of the work, the lines of least resistance being 20 feet and downwards, the charges in lbs. were—

$$\frac{\overline{L.L.R.}^3}{10} \text{ and } \frac{\overline{L.L.R.}^3}{15}, \ldots\ldots\ldots\ldots (9),$$

the former too violent the latter too weak.

At Cuxton, near Chatham, in chalk rocks rather more than

$$\frac{\overline{L.L.R.}^3}{27} \text{ and } \frac{\overline{L.L.R.}^3}{20}, \dots\dots\dots\dots\dots\dots\dots\dots (10)$$

were the charges used in lbs.

Rankine gives in lbs. the charge for powder

$$\frac{\overline{L.L.R.}^3}{10} \text{ to } \frac{\overline{L.L.R.}^3}{82}, \dots\dots\dots\dots\dots\dots\dots\dots (11).$$

In Table No. II. for dynamite, the charge in lbs. varies from

$$\frac{\overline{L.L.R.}^3}{82} \text{ to } \frac{\overline{L.L.R.}^3}{116}, \dots\dots\dots\dots\dots\dots\dots\dots (12).$$

Nobel's No. 1 dynamite cartridges are from ⅞ to 1 inch in diameter, 3½ inches long, and each weighs 2 ozs. and 2½ ozs. respectively: they are intended to be used in 1 inch holes. Where holes of larger bore are drilled, the dynamite should be taken out of its parchment wrapper, dropped into the hole and squeezed with the wooden rod so as to completely fill the hole.

The following Table will, it is hoped, be useful in employing dynamite.

Diameter of the bore hole.	Dynamite in one lineal inch of hole.		Dynamite in one foot of hole.		Depth of hole to contain one lb. of Dynamite.
Inches.	Avoirdupois.		Avoirdupois.		Inches.
	lbs.	ozs.	lbs.	ozs.	
1	0	0·670	0	8·040	23·880
1½	0	1·507	1	2·084	10·617
2	0	2·682	2	0·184	5·966
2½	0	4·189	3	2·268	3·820
3	0	6·032	4	8·384	2·652

Firing by Electricity.—The method of exploding charges of dynamite by means of electricity should generally be adopted except in isolated small holes: it should generally be used when the holes are from 4 to 6 feet deep, as then the quantity of material blasted will be considerable, because the loosening of the whole rock will be more complete than if each bore hole were fired separately; thus the whole cost of removing the blasted material will be considerably reduced. It requires more intelligence than is usually possessed by a *maistry* to fire charges by electricity, and the fuzes used with the battery are expensive, costing Rs. 5 per dozen. But any Overseer ought to be easily able to use a battery.

Holes to be fired simultaneously should be so situated as to cut into one another when exploded, thus assisting each other in doing the work. One advantage of simultaneous firing is that it matters little if one hole is undercharged and another overcharged, because all the holes may be considered as acting together, and generating *one* explosion: the hole that may be overcharged thus assists that which is undercharged.

The *full* lines in the sketch in *Fig.* 19 show the probable line of fracture with simultaneous firing, and the *dotted* lines show the lines of fracture when the holes are exploded separately. It will be seen that each charge has much more work to do when fired independently than when 3, 4 or 5 holes are exploded simultaneously, and that the blasting of the rock is not so complete, leaving the portions shaded without throwing them out. Since the charges of dynamite have not so much work to do when fired simultaneously as they have when separately fired, they may be somewhat less than when fired independently, thus saving in dynamite.

Miss-fires being more likely to happen with electricity than with Bickford's fuze, water tamping should always be used when firing by electricity, to enable the fuze to be removed from the bore hole in the case of a failure to explode. Should any hole miss-fire, the electric fuze should not be removed until after another trial has been made to explode it with the battery; the second trial will, as a rule, be found to succeed, as miss-fires are more often due to a weak current and imperfect insulation than to any other cause.

The simultaneous exploding of holes will often be very useful in sinking and deepening wells, because the material is so much tied in, that it can only be got out by firing a number of holes at one time. Even when the holes are sloping, good results can best be obtained by simultaneous explosions.

Nobel's Company supply magnetic exploders to fire 6 holes at once at a cost of Rs. 200 each.

Dynamite should supersede Powder.—In conclusion, it appears clear, from the experiments herein recorded, that dynamite ought everywhere in India to supersede gunpowder in all such operations as those for which powder is usually now employed, and which are indicated in the first paragraph of this Report. But, in quarrying for stone for building, gunpowder seems preferable, owing to the shattering and splitting effect of dynamite, which, if used for such a purpose, would probably injure more stone than it threw out in a sound state.

Mr. Milne's services acknowledged.—I cannot conclude this Report without very cordially acknowledging the great assistance cheerfully afforded me by Conductor and Sub-Engineer Mr. A. Milne. His aptitude in Surveying and Levelling, and skill in Drawing have been of the greatest use; and he has zealously and intelligently conducted the experiments to my entire satisfaction.

J. L. L. M.

Proceedings of the Madras Government, Public Works Departm

READ the following :—

From the Supdg. Engineer, 2nd Circle, No. 187, dated 26th July, 1880.

Memo. by the Chief Engineer, P. W. Department, dated 12th August, 1880.

Order thereon, 23rd August 1880, No. W.

THE Government are satisfied from the foregoing report that the o with which the assignment of Rs. 1,000 was made, in G. O. of October, 1879, No. 2686 W, has been attained, and has demonstrated superiority of dynamite as an explosive agent, well adapted for mos the operations, in which gunpowder has hitherto been employed, in execution of Public Works.

2. The report will be communicated to the Military Department t the question of employing this material as part of the future equipm of Sapper and Miner Companies and Engineer Field and Siege Pa may be considered.

3. The Judicial Department and the Railway Branch of the P. Department will be asked to consider the propriety of allowing dynam to be carried by Steamers and Railways with letter mails on the sa footing as gunpowder.

4. The thanks of Government are due to Major Morant for his v able and exhaustive report, as also to Conductor Milne for the part tak by him in conducting the experiments.

5. A sufficient number of copies of the report* will be printed fo use of the P. W. Department, and for circulatio to the several Governments named in the margin,† with 50 added for the general public purposes o Government.

* Without the plans or detail of experiments.

† * * * *

(True Extract).

(Sd.) R. H. SANKEY, COL., R.E.,

Secy. to Govt., P. W. D.

To the Supdg. Engineer, 2nd Circle, for early communication to Major Morant, Royal Engineers.

No. $\frac{824}{W.C.}$

Communicated to Major Morant.

(Sd.) W. R. MEAD, MAJOR, R.E.,

Dated 24th August, 1880. *Supdg. Engineer, 2nd Circle.*

(True Copy).

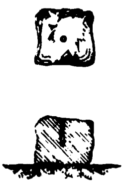
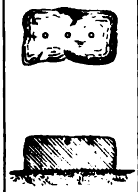
(Sd.) J. L. L. MORANT, MAJOR, R.E.

er the various conditions shown.

For boulders by ounces to square feet of least vertical section.

Explosive employed.

Nobel's Dynamite No. 1.

	ILLUSTRATIONS.				
Loose *etached* *rocks.*					
ifferent nditions of oulder asting.	Vertical hole bored in detached boulder to proper depth i.e. ½ height of rock.	Vertical hole bored ½ height of rock in depth.	Several vertical bore holes ½ height of rock in depth and 3 feet apart.	Dynamite laid on rock with no bore hole and covered with clay, &c.	Dynamite laid on rock and exploded without being covered.
oulders.	*Explosive charges of Dynamite in ounces Avoirdupois.*				
a of least tical section in are Feet.	*One* ounce of *Dynamite* to every *4* square feet of least vertical section.	*One* ounce of *Dynamite* to every 2 square feet of least vertical section.	*One* ounce of *Dynamite* to every *square foot* of least vertical section.	*Two* ounces of *Dynamite* to every square foot of least vertical section.	*Four* ounces of *Dynamite* to every square foot of least vertical section.
are Feet.	Ounces.	Ounces.	Ounces.	Ounces.	Ounces.
2	½	1	2	4	8
4	1	2	4	8	16
8	2	4	8	16	32
12	3	6	12	24	48
16	4	8	16	32	64
20	5	10	20	40	80
24	6	12	24	48	96
28	7	14	28	56	112
32	8	16	32	64	128
36	9	18	36	72	144
40	10	20	40	80	160
44	11	22	44	88	176
48	12	24	48	96	192
60	15	30	60	120	240
70	17½	35	70	140	280
80	20	40	80	160	320
90	22½	45	90	180	360
100	25	50	100	200	400

ALFRED NOBEL'S DYNAMITE.

kford's Fuse

Fig. 2A.

Fig. 3A.

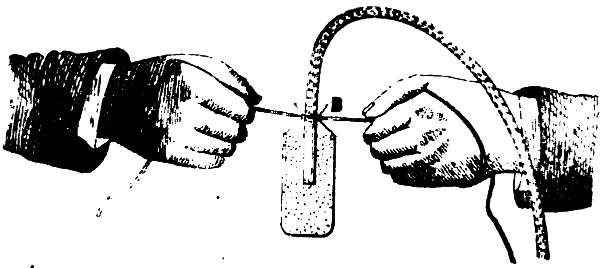


Fig. 4.

Fig. 5.

Fig. 7.

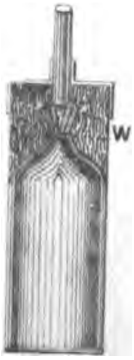
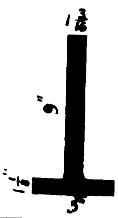


Fig. 8.

Fig. 9.



THOS. D. BONA, Supdt

ALFRED NOBEL'S DYNAMITE.

FIG. 10.

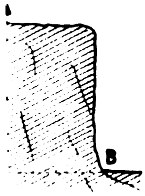


FIG. 11.

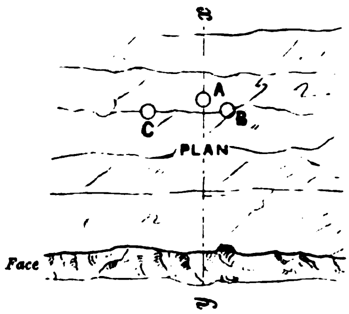


FIG. 12.

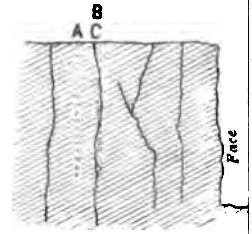


FIG. 13.

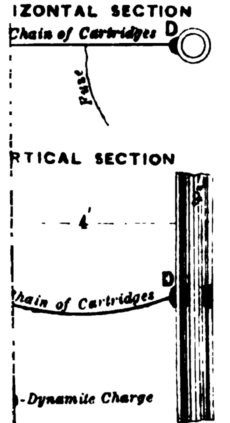


FIG. 14.

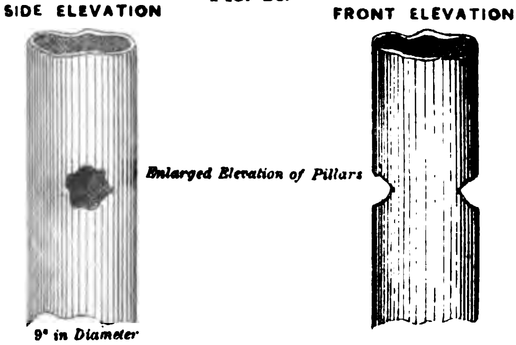


FIG. 16.

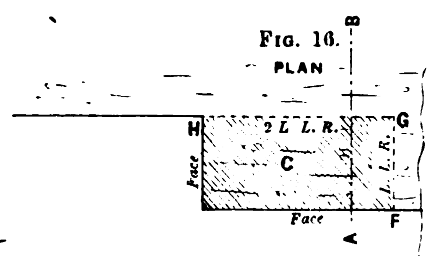


FIG. 15.

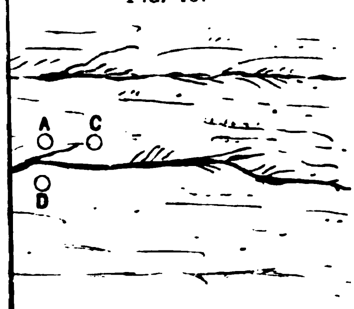


FIG. 19.

PLAN OF ROCK WITH FACE

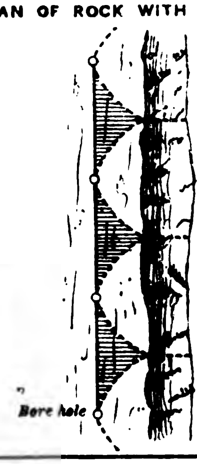


FIG. 17.

SECTION ON AB.

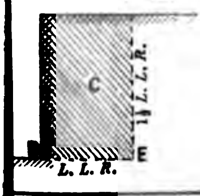
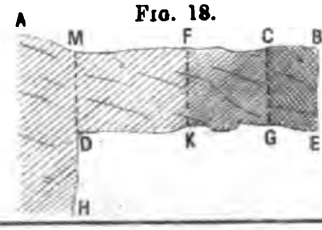


FIG. 18.



Press, Roorkee.

THOS. D. BONA, Supdt

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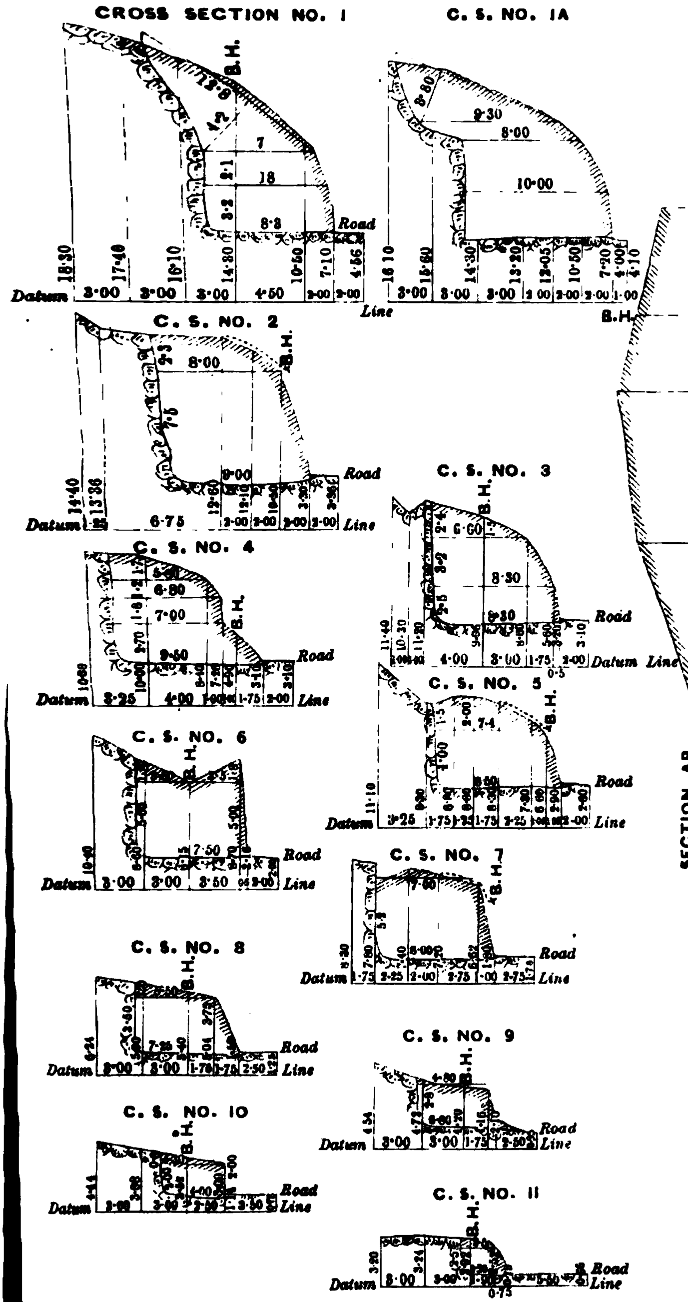
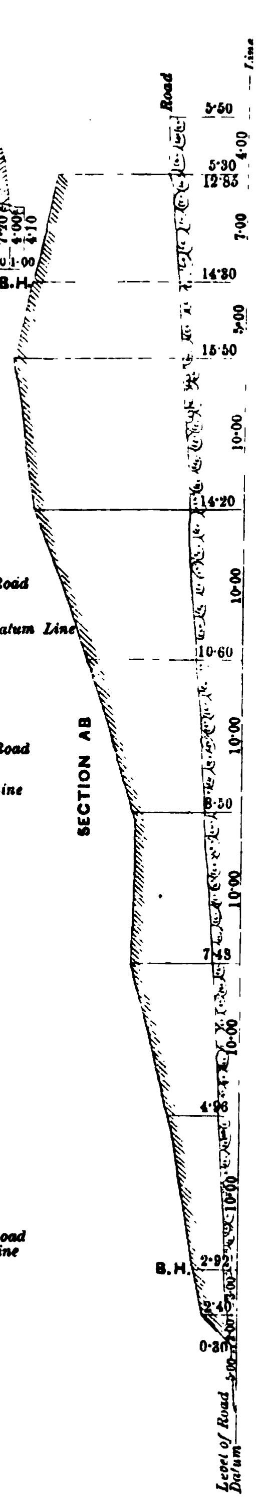
ALFRED NOBEL'S DYNAMITE.

Scale, $\frac{1}{150}$ *or* **12·51"** *to an inch*





REMARKS.

3378 Cubic feet of Rock Blasted.
606 Ozs. of Dynamite used.
86 No. of Bore Holes.
155 Rupees Total Cost.
Rs. As. P.
4 9 - 5 Cost per 100 cubic feet
Rock Blasted and Removed.

THOS. D. BONA, *Supdt.*

No. CCCXXXIII.

REPORT ON THE ULSOOR WATER WORKS.

[*Vide* Plates I.—VI.]

By Lieut. F. J. Romilly, R.E., *Exec. Engineer.*

Dated Bangalore, 30th September 1879.

The "Ulsoor Water Works" is the system by which the barracks occupied by the European troops stationed at Bangalore are supplied with water for all domestic purposes. Commenced about 18 years ago the system is now complete, (with the exception of a few minor details,) but during the progress of the work the original arrangements have been subject to many modifications, and in reporting upon the works, it is purposed to give as brief a history as possible of the project from its commencement, describing the modifications or additions to the scheme in order as they occurred.

The Ulsoor rock project, which is the basis upon which the existing scheme has been constructed, was drawn up by Lieut. H. Tulloch, R.E., (Madras) in 1862. The idea of the project seems to have been suggested by Colonel Green when discussing the Nundidroog scheme, who suggested supplying the Cavalry barracks from the Ulsoor tank, by raising water from it in four lifts of from 8 to 10 feet each, and in Lieut. Tulloch's project the Ulsoor tank was proposed as a source of water supply to the garrison. It may here be observed that a scheme for constructing a masonry sewer to carry the drainage of the Cantonment Bazaar, which up to this time had discharged into the Ulsoor tank, under and away from the tank was approaching completion, so that contamination of the tank water by sewage matter, one of Colonel Sir A. Cotton's objections to this tank as a source of water supply, was no longer to be apprehended. The sewer was completed in 1864.

The objects which the project proposed to carry out were as follows:—

(1). To supply water pure and fit for all purposes to all the barracks occupied by European troops at Bangalore.

(2). To supply it in unlimited quantities.

(3). To bring the supply within reach of every soldier.

(4). To carry the water supply inside every lavatory, bath-room and cook-room, and arrange for its being there drawn for use by simply turning on a tap.

(5). To provide for the storage of one month's supply at every barrack, to be kept ready for use in the event of any emergency.

Source of Supply.—Before proceeding further, it will be as well to describe the *Ulsoor tank*, the source of supply from which the project takes its name.

The Ulsoor tank is situated at the north-east end of the Cantonment of Bangalore, and is supplied by two feeders which enter the tank at its north and west extremities, the latter feeder being also the main drainage channel of the Cantonment Bazaar. The legitimate gathering ground of the tank amounts to about 3,700 acres (say 5 square miles), but about $\frac{1}{10}$th of this, or 370 acres, is intercepted by feeders constructed to convey the drainage into reservoirs constructed by the Mysore Government during 1863-66, and situated at the western end of the valley of the western feeder. These reservoirs are intended to supply the Mysore establishments and population of the town, and form part of a project in course of execution by the Mysore Government. The gathering ground of the tank consists of red soil or decomposing feldspathic rock exceedingly porous and friable.

The following statistics regarding the effect of rainfall upon the tank and gathering ground are interesting. In 1871, 29 inches of rain fell in 32 weeks, but in 13 weeks only was there any perceptible rise in the tank noted (nothing under 0·25 inch being recorded).

The total rises amounted to 50·25 inches, or as about 24 inches were taken out for the troops during the year, say 74·25 inches for a total rainfall of 29 inches, equivalent to an average rise of 2·56 inches per inch of rainfall.

Out of the total rainfall of 29 inches, 12 inches falling in showers had individually no effect on the tank.

Five inches falling in heavy showers raised the tank 5 inches in separately appreciable quantities.

Twelve inches falling in heavy connected showers gave the tank 33 inches of rise, or 21 inches from the gathering ground, and 12 inches by direct rainfall.

The tank being taken at 124 acres, and the gathering ground at 5 square miles, the 12 inches of rain would only give ·8 inch of rain as collected from the surface and as reaching the tank.

In August 1878 a rainfall of 5·75 inches in 24 hours raised the tank 2 feet 8·5 inches in the same time, equivalent to ·9 inch on the catchment. Evaporation during rainy weather is at the rate of 1·2 inch per week.

The waste weir of the tank is placed at the south extremity, where the contour of the margin forms a deep triangular bay. It consists of a body wall of dressed stone with piers at 10 feet clear interval forming a bridge of 9 vents, by which the road along the eastern margin of the tank is carried over the surplus channel. The total available waterway of the weir is 90 running feet. Until 1877 the weir was provided with upright stones and shutters, by which water could, if desired, be held up to 2 feet above the (then) Cody (or Calingula crest) level. These shutters were last used in 1872. In 1877 the upright stones were taken out and laid flat on the weir crest, thus raising it 9 inches, and increasing the capacity of the tank by 21 million gallons, and also slightly increasing the waterway of the weir. The weir has a clear overfall, and the maximum head on the weir recorded is 2 feet, and the discharge with such a head would be 805 cubic feet per inch, or 68,552,000 cubic feet in 24 hours. The maximum recorded rainfall at Bangalore is under 6 inches in 24 hours, which would give 69,696,000 over the gathering ground of 5 square miles. Suppose half of this to reach the tank, which from the statistics given above is in excess of what may be expected, the weir could discharge it in less than 24 hours.

A prominent natural feature connected with the tank is the "rock," a collection of large boulders of stratified rock rising abruptly out of the tank with a steep "strike" in the middle of the eastern bund, about 400 yards north of the waste weir. The summit of the rock is about

43 feet above the crest of the weir, and on the top is a small pagoda about 10′ × 10′ and 12 feet high.

In August 1862, when the report on the proposed project was submitted to Government, it was stated that the area of the tank was 490,000 square yards, and in some parts 30 feet deep, while when water stood at its usual level the depth was nowhere under 8 feet. Assuming this as the average depth, the capacity was calculated to be 490,000 × 27 × 6¼ = 82,687,100 gallons. In 1872 the tank was surveyed, and soundings taken on six sections, when it was found that the deepest part was 10·98 feet only below waste weir level. On 20th November, 1876 there was only 2 feet 2⅝ inches of water at the deepest part, and the water level at that time being 7 feet 1⅞ inches below cody level, the bed of the tank at its deepest part was only 9 feet 4½ inches below the crest of the weir. Supposing all these figures to be correct, they show that between the years 1862–1872 the deepest part of the tank had silted up 19·02 feet, and 1·56 feet between the years 1872–1876. It seems impossible, however, that the bed could have silted up 19 feet in 10 years, and it is more probable that the depth of 30 feet assigned to the deepest part in 1862 was overstated by mistake. In the early part of 1877 when the tank was quite dry, numerous and careful measurements were taken, when the following data were deduced :—

Area of tank	= 124 acres.
Average depth	= 7·68 feet.
Greatest ,,	= 11·85 feet.
Cubical content	= 41,501,008 cubic feet.
Capacity	= 259,381,302 gallons.
	= 260 million gallons say.

When these measurements were made the weir crest had been raised as stated above, so that the capacity of the tank with the original crest level would be 239 million gallons, nearly three times as much as what was assumed in the report of 1862.

During the late famine in 1876-77 when the tank was quite dry, advantage was taken to remove the silt and improve the tank. A road bund already existed along the south-east and north margins, and the bed was deepened, and a road bund formed along the western margin also.

With a view to check the deposit of silt brought down by the feeders, it was proposed that the north portion of the tank at the tail of the north feeder traversed by the north bund or roadway should be converted into a silt trap or settling basin, and that the new bund on the west should be so aligned near the western corner of the tank as to form a second settling basin at the tail of the western feeder. Both proposals were carried out, but the former one was still further developed. It was ascertained that the capacity of the tank could not be increased by further raising the waste weir, as a portion of the cantonment immediately above the waterspread of the tank would thereby be flooded. It was accordingly determined to supplement its supply by constructing a subsidiary reservoir across its northern feeder, (in other words by increasing the capacity of the settling basin mentioned above,) in which drainage could be impounded after the Ulsoor tank had been filled, and used subsequently to replenish the tank. This reservoir was constructed as a famine relief work. A bund has been thrown up along the north side of the road traversing the north end of the tank, provided with a waste weir 62½ feet long of dressed stone with an ogee apron, and fitted with a vent at one end 18″ × 24″, closed by a shutter for passing water to the tank when necessary. The crest of this weir is 5 feet 4 inches above the crest of the Ulsoor weir. The valley above the new tank has an area of 1,130 acres, from which a run off of 6 inches in the year may be calculated on giving a supply of 35,000,000 cubic feet. The capacity of this subsidiary reservoir is 10,000,000 cubic feet, or 62,500,000 gallons, very nearly one-quarter the capacity of the Ulsoor tank.

The bunds of the tank are of good section throughout, the north-east and south banks being metalled, forming part of the Cantonment roads. The south and a portion of the east road bunds are low, and should be raised, water standing 2 feet on the weir crest would probably wash over them. The east bund from the escape to the rock and 300 yards beyond it is revetted with a rough stone wall and parapet on the tank side.

In 1862, when the Ulsoor rock project was being worked out, samples of the tank water were compared before and after filtration with the Madras waters of Egmore and the seven wells, a comparison that was favourable to the Ulsoor water, and showed that its principal impurities were iron and silica, the latter being almost, if not altogether, insoluble, and giving the water a muddy appearance. The presence of iron would render the water beneficial on sanitary grounds, and the silicates are the very portions that would be removed by mechanical filtration. This was proved by filtering the water through 6 inches sand, 6 inches charcoal, and 6 inches gravel, when it came out perfectly clear. The total residue, organic and inorganic, was 30·2 grains per gallon as compared with 41 grains, and 98·4 grains per gallon in the Egmore and seven wells waters respectively. In 1863 a sample of the water was sent to Assistant Surgeon Nicholson, R.A., at Calicut, for analysis, who found that the water contained chlorides of sodium, carbonates of lime, magnesia, silica, and alumina, with a little iron and organic matter. It may here be noted that at the time that Assistant Surgeon Nicholson made this analysis, he was not aware of the source whence the sample of water sent to him for examination was taken.

About 1868 the tank water seems to have obtained a bad reputation, and in a G. O., dated 12th December, 1870, it is stated that "the water of the Ulsoor tank even after filtration is unfit for drinking or culinary purposes." This change of opinion regarding the fitness of the tank water for supply to the troops would seem to be the result of a report by the Chemical Examiner upon some samples of the Ulsoor tank water bottled by the President of the Municipality, and sent to Madras for examination. The bottles arrived with their contents in an advanced state of decomposition and stinking abominably, so that the Examiner came to the conclusion that the tank water contained fæcal matter. This report caused a complete revolution in the execution of the water supply project then in progress, which will be described further on.

In 1871 and 1872 by the orders of Government, a very careful and complete analysis of the Ulsoor tank water was conducted by Assistant Surgeon Nicholson, R.A., at Bangalore, whose investigations and reports were further verified and commented upon by the Chemical Examiner and Sanitary Commissioner. The conclusions arrived at were that the tank water contained *no* fæcal matter, and after filtration was perfectly wholesome and fit for drinking purposes. The water was found to deposit on standing the small quantity of very fine clay and sand which renders it opalescent. The small amount of chlorine, the total absence of nitric and nitrous acids and ammonia showed the water to be free from mineral remains, which would evidence any former sewage contamination, and the amount of organic matter present was found to be very small.

The suspended matter, besides the sand and clay noticed above, consisted also of conferval vegetation, which, when ripe, agglomerates into a green scum, and which when blown into corners of the tank is liable to ferment and evolve the disagreeable smell peculiar to sea and fresh water algæ. It was the presence probably of some of this green scum in the samples of tank water sent to the Chemical Examiner for analysis about 1868 that led to the idea of fæcal contamination of the lake water. The confervæ being a highly nitrogenized substance, would, in decomposing, resemble in colour and smell decomposing sewage matter, and in the absence of additional evidence, would very naturally be mistaken for such. It is worthy of note that the analysis of the tank water made by Dr. Nicholson in 1871, compared with his analysis of the same water in 1863, showed that the water had improved since the first examination was made. His analysis in 1871 showed greater freedom from chlorides and organic matter, probably due to the working of the main sewer which had been constructed in the interval, and to greater care in the arrangements for diverting suspicious drainage from the tank. The comparative freedom from organic matter speaks well for the conservancy Cantonment Bazaar, the surface drainage of which passes into the tank by the western feeder. The mineral characteristics of the water were the same as observed in 1863. The living organisms found in the water were trifling, some water fleas and infusorial animalcules.

The Ulsoor Rock Water Supply Project.—The details of the project may be stated briefly thus—

The source of supply was to be the Ulsoor tank, the rock was selected for the site of the head works.

The water was to be drawn from the surface of the tank at its deepest part, which is immediately opposite the rock, by a steam engine erected on the rock, at about 10 or 12 feet above high water level. The tank water was first to be pumped into four settling beds, each capable of holding three days' supply for the troops, so that 12 days would elapse before clear water was drawn off from any one settling bed. From the settling beds clear water was to be pumped up by the same engine to a large filter erected on the top of the rock, capable of filtering three days' supply in 24 hours. From this filter the water was to be conveyed by gravitation by earthenware mains to service cisterns, each capable of holding a month's supply for the barracks at which they were severally erected. From these cisterns the water was to be conveyed by distributing pipes to each lavatory, bath-room and cook-house, and all other places where it might be desirable. Drainage pipes were to be laid down to carry off refuse water into existing drains. It may be observed that the successful working of this scheme depends upon the summit of the rock having a command of about 10 feet above the planes of site of the various barracks.

The European force stationed at Bangalore being as follows :—

1 Regiment of Cavalry......A,
1 " Infantry......B,
1 Battery Horse Artillery C,
2 Batteries Field " D,

the number of souls (including women and children) and horses to be supplied would be for

A.	1,200	souls	and	800 horses.
B.	1,200	"		Nil.
C.	400	"	and	300 horses.
D.	200	"	and	150 "
Total, ...	3,000	"	and	1,250 "

The daily demand was fixed at 10 gallons per head and 8 gallons per horse, and the daily consumption at the several barracks would be by the

	Gallons.
Cavalry, ...	... 18,400
Infantry, ...	... 12,000
Horse Artillery, ...	... 3,200
Field "	... 6,400
Total,	... 40,000

Allowing 50 per cent. for waste, the daily supply to be allowed was fixed at 60,000 gallons, which required a monthly supply of 180,000, and a yearly supply of 21,600,000 gallons.

This estimate showed that the source of supply was practically unlimited, the capacity of the tank being shown in page 4 to be 260,000,000, equivalent to more than 10 years' supply on the above demand. It is noted in the above data that the requirements of the native followers of the troops were not taken into account.

The estimated cost of this project was Rs. 72,000, but the estimate included amounts for the construction of plunge baths and lavatories, which are only indirectly connected with the project for water supply. Neglecting these items, the actual estimated cost of the works necessary to collect and supply water to the European troops was as follows :—

	Rs.
1 Main filter, ...	12,000
4 Settling beds, ...	6,000
4 Service cisterns, ...	19,000
1 Engine and pumps, ...	9,000
1 Engine house, ...	5,000
Earthenware mains, ...	5,000
" delivery pipes, ...	1,000
Cocks, ...	1,000
Sundries, ...	2,000
Total Rs.,	60,000

The Engine.—A 12 horse-power (nominal) engine with pumps had been indented for in August 1859 for raising water from the fort ditch at Madras, and had been shipped from England in May 1861. As it was not likely to be required for some time at Madras, it was assumed that it would be immediately available for the Ulsoor water works.

The force pump of the engine was to be placed one foot above the high water level of the tank, and in a most unfavourable season it was assumed that the water might fall 12 feet below this. The top of rock being 44 feet above high water level, and the bed of the filter being placed 5 feet above this again, and the depth of water to be maintained in the filter being 6 feet, the total lift would be $12 + 44 + 5 + \frac{6}{2} = 64$ feet.

The capacity of the filter as elsewhere stated was to be 160,000 gallons, which would have to be pumped up daily. In anticipation that contingencies might arise to increase the demand, such as an addition to the Military force at Bangalore, or future extension of the works to supply the town, it was assumed that the engine might be called upon to pump up as much as 200,000 gallons daily. Supposing the engine to work eight hours a day, and the unit of horse-power to be 33,000 foot lbs. per minute, and one gallon of water to weigh 10 lbs., the horse-power required is $\frac{200,000 \times 64 \times 10}{33,000 \times 60 \times 8} = 8\cdot08$ horse-power. Allowing 25 per cent. for loss of power in pumps owing to inferior power in fuel, imperfect superintendence, &c., about 10 horse-power would be required. The 12 horse-power engine proposed to be used was, therefore, ample for the requirements of the project or for possible future requirements.

The Filter.—The filter was to be placed on the top of the rock. In order to keep the cisterns at the barracks constantly full, and to provide against leakage, evaporation, waste, the principal filter would have to be capable of supplying three or four times the estimated daily consumption. Experience at the Howrah Water Works in Bengal showed that 30 feet super of filtering media will filter 1,000 gallons in 24 hours. The filter was designed with an area of 4,800 square feet, and was to have a depth of 6 feet when full. This would hold $4,800 \times 6 \times 6\frac{1}{4} = 180,000$ gallons, and filter daily $\frac{4800}{30} \times 1,000 = 160,000$ gallons, providing therefore an ample supply of pure water. To adapt the filter to the form of the summit of the rock, it was designed in the shape of an irregular pentagon, divided into two parts by a cross wall, so that either part could be cleaned or repaired without interrupting the daily supply, each part being capable of holding 80,000 gallons. The following is a brief description of its proposed construction.

The walls were to be built of brick in hydraulic mortar throughout, the inner faces vertical, the outer faces with a uniform batter to the bottom of the foundations, the latter being built without offsets. After the walls were constructed, stiff clay was to be thrown in and well puddled to bring the surface of the rock enclosed to the level of the highest point of the rock. Above the clay a layer of concrete one foot thick, next a flooring of best pottery clay bricks on edge without mortar supporting another layer of bricks laid flat. Above these 6 inches of coarse stone and gravel, and 6 inches of fine stone and gravel. Next 12 inches of animal and vegetable charcoal, and finally 12 inches of fine sand covered with a thin layer of clay to prevent the sand being disturbed by the water passing into the filter. The total thickness of filtering media was 3 feet. To allow of the escape of air, an accumulation of which below the filtering media has sometimes been known to hamper the action of a filter, it was proposed to erect bamboo air shafts at intervals.

The Cisterns.—There was to be a cistern at each barrack, four in all, each capable of holding one month's supply, and each divided into two compartments by a cross wall to allow of repairs being carried out without entirely stopping the supply. There are none of the original plans in the office for me to refer to, but it would appear that they were designed by Lieut. Tulloch with walls *and* foundations of brick in hydraulic mortar, with a flooring of brick 6 inches thick over a layer of concrete 12 inches thick. The chief feature in them was an arrangement for promoting a current in the water, and preventing stagnation, by cross walls at intervals of 25 feet with arched openings at the alternate ends, so that water entering the cisterns at one end would have to flow in a zig-zag course to pass to the outlet pipe at the other end. The cisterns were not provided with roofs.

The Mains.—These were to be 8 inches earthenware socket pipes, placed 3 feet below the surface of the ground. It was calculated that the greater part of the pipes would not be subjected to a pressure of more than 15 feet head of water. About 600 yards would have to bear a pressure of about 50 feet. This was considered well within the limits of what earthenware pipes could bear, pipes of this material having been used in France with a head of 150 feet, and ascertained in England to burst only under a pressure due to 1,500 feet. The joints were to be packed with asphalte, or cement of 5 lbs. of cast-iron filings to 2 ounces of sal ammoniac.

In working out the project, it was found that the site of the old Dragoon barracks (now occupied by the European Infantry) was higher than the top of the Ulsoor rock. To obtain the required command, it was proposed to utilize the small pagoda on the top of the rock, situated within the site for the main filter, and to convert it into a small auxiliary reservoir on a higher level, into which the filtered water required for these particular barracks could be pumped by the engine, and gravitate to the barracks. The pagoda it was understood was no longer considered sacred or resorted to by the natives.

Sanction of the Project and commencement of the work.—The above project was sanctioned by Government on 12th February, 1863, and work in connection with the scheme commenced in April of the same year.

The cisterns at the Royal Horse Artillery and Royal Artillery barracks and new Cavalry barracks during 1863-65, but in carrying out the work considerable modifications seem to have been made on the original designs prepared by Lieut. Tulloch, viz., by the omission of the cross walls to ensure a free circulation of water, the use of ordinary in place of hydraulic lime, and the substitution of stone for brick in the foundations and basements. These deviations appear to have been sanctioned by the Superintending Engineer on the proposals of the Executive Engineer in charge of the work. The substitution of stone in the foundations was suggested, owing to a difficulty in obtaining good table moulded bricks readily.

In March 1865 Lieut. Tulloch, R.E., who assumed charge of the Division, called attention to these deviations from his original design. He pointed out that stone is seldom used in the walls of reservoirs, as cement does not bind properly with it, and as this material was introduced at the bottom of the wall, where the pressure is greatest, he expressed his opinion that the cisterns when filled would leak.

First revision of the Project.—Up to the end of August 1864 the total expenditure on the original project was Rs. 23,738, and in September of that year a revised estimate was submitted by Lieut. Pennycuick, R.E., amounting to Rs. 1,46,300, or more than double the original estimate. The main idea of the revised project was identical with that of Lieut. Tulloch's original scheme, viz., to supply the barracks with water drawn from the Ulsoor tank, and pumped into a filter on the top of the rock, to descend thence by gravitation to the cisterns at the barracks, but the following modifications on the original estimate were introduced :—

(1). Cast-iron piping was substituted for earthenware in the mains, and a 9-inch main was provided instead of an 8½-inch, on account of the sizes of castings in the market.

(2). Lead piping was substituted for earthenware for minor distribution, and this was further extended to detailed house service in married quarters in lieu of the stand cocks proposed by Lieut. Tulloch.

(3). Alteration in the arrangements of the cistern at the old Dragoon barracks, which needs description.

It had been found that not only would the floor of the proposed cistern here be 3·86 feet below the floor of the filter at the rock, but that it would be in some cases as much as 8 or 9 feet below the floors of lavatories in the barracks which it was to supply. Lieut. Tulloch, it will be remembered, foresaw this difficulty, and proposed to meet it by means of an auxiliary cistern on the pagoda on the Ulsoor rock. The idea, however, would not seem to have been regularly worked out in detail in the original project, and it was found subsequently that not only was the pagoda far too small to allow of a reservoir of suitable capacity being erected on it, but also that the natives did regard it with veneration, and objected to its being meddled with.

Lieut. Pennycuick proposed to overcome the difficulty by having a double cistern at the Infantry (old Dragoon) barracks, one with its floor 6 feet below the ground, to be filled by gravitation from the filter on the rock, and a second one of similar capacity close by with its floor raised 10 feet above the ground level, so as to command the barrack buildings, and to be filled from the lower cistern by a local wind engine. Lieut. Pennycuick also called attention to the flooring of the cisterns already built, and which appear to have been constructed of concrete, covered with a layer of earthenware slabs 6 inches thick. He expressed his opinion that this flooring was too slight, and provided for granite stone flooring set in asphalte in the cisterns designed by him, and suggested its adoption in the other cisterns also.

A slight alteration was introduced in the nature of the filtering material. In the original project it was specified that animal charcoal was to be used as well as vegetable. The contractor who provided the material mixed human bones with the bones collected for obtaining charcoal. This was condemned by a Medical Committee assembled to consider the subject, and to prevent the recurrence of such an evil, the use of vegetable charcoal exclusively was decided upon.

As previously stated, the revised estimate amounted to more than double the original scheme as first proposed by Lieut. Talloch. The excess was due mainly to the substitution of cast-iron and lead for earthenware piping, the greater extent of minor piping owing to the more elaborate minor distribution, and the alteration in the arrangements to the cisterns at the Parade (Dragoon) barracks.

At the time that the revised estimate was submitted, the following was the condition of the work :—

The engine house was nearly complete, its progress had been delayed by difficult blasting. The engine driver's quarters were complete. The brickwork of the filter on the top of the rock was complete to floor level. The brickwork of the Royal Horse Artillery and Royal Artillery cisterns were complete, the flooring remaining to be done. The foundation and basement of the Race Course barracks cistern was complete.

Second revision of the Project.—I am unable to trace from the records in the office what orders were passed upon this revised estimate submitted by Lieut. Pennycuick, but it would appear that it was partly carried out, as in April 1865 the flooring of the filter on the rock was completed, and the cistern below ground level at the old Dragoon barracks built. As regards the difficulty of obtaining a proper command over the buildings in the Parade barracks by means of the filter on the top of the Ulsoor rock, the suggestion for overcoming this difficulty by the double cistern and wind engine at the Parade barracks proposed by Lieut. Pennycuick was not approved by Government, and the whole scheme was recast and took its present shape.

The filter on the top of the rock was abandoned, and it was determined to pump the water from the tank into a filter at the foot of the rock, to pass from thence by gravitation to a pure water basin close to the filter and at the edge of the tank, whence the same engine was to pump the pure water up to a stand pipe on the top of the rock, of sufficient height to command all the buildings to be served, and from which it would flow to the cisterns already built. The settling beds were omitted from the arrangements. These arrangements have been carried out, and are now in force. The necessary works appear to have been commenced before the plans and estimates for them were completed.

During 1865-66 the engine and pumps were set up, and the engine house built, the filters and pure water basins were commenced, and completed in the following year, when the pipes, valves, &c., were received from England.

The laying of the pipes to the cisterns on the old race course was completed by May 1868, but on testing them they were found to leak at the joints to such an extent that it was necessary to take them up and relay them. In relaying them the following precautions were adopted to ensure the joints being water-tight. The pipes were laid in lengths of about 100 yards at a time, the joints being left uncovered, and each length tested by closing the free end of the piping, and then pumping in water until a jet of water appeared at the top of the stand pipe. The joints were carefully examined during the test, and any found to leak replaced before another length of piping was laid and similarly tested.

Failure of Cisterns and Filters.—In November 1868 the cisterns at the Royal Horse Artillery and Cavalry barracks were filled, but at the first attempt to deliver the water, although all the piping was found to be water-tight, the cisterns themselves showed signs of giving way, and pumping had to be stopped. The Superintending Engineer in reporting upon this failure expressed his opinion that the thickness of the cistern walls and the depth of the foundations was insufficient, but as the cisterns began to leak before they were half full, the immediate cause of failure was to be attributed to bad work in the flooring.

To remedy this defect it was proposed to remove part of the flooring, and to excavate a trench 12 inches broad, carried down to 12 inches below the toe of the walls inside, and to fill this with concrete, to cover the existing floor with 12 inches of masonry (brick or tile) set in partially hydraulic lime, the ends of the new floor to be curved up at the junction with the walls, to carry this masonry up to the top of the walls for a thickness of 9 inches, and to plaster the whole with Portland cement.

The filter at the foot of the rock was also found to leak, and similar remedies were proposed to be carried out to repair it.

The cost of these repairs was estimated at Rs. 34,000, and an additional height to the walls of 18 inches was given to make up for the diminution of their capacity by the interior lining and extra thickness of floor. It was proposed to carry out the repairs first to half of the cistern at the Royal Horse Artillery barracks. This cistern was selected for trial, as its southern half rested on a basement 4½ feet, so that any insufficiency in the proposed method would be more likely to become apparent from the failure of the flooring on the deep filling in of the basement. The repairs to this half cistern were completed, and the cistern filled on 7th May, 1870, when no leakage was apparent.

The measures proposed having met with success in this case, the same method was sanctioned for the remaining cisterns and the filter, and with the following results. With the second half of the Royal Horse Artillery cistern, as with the first, they were successful, and also in the case of one-half of the cistern at the Cavalry barracks and half of the filter. In the case of the second half of the Cavalry cistern and the filter the repairs failed utterly. The work of the new flooring was found to be of excellent quality, the cement being so hard that it turned the point of the pick used in cutting out the masonry to examine the cause of failure, and the failure was attributed entirely to the excessively bad quality of the old flooring, which gave way under the weight of the water pumped into the cistern and filter, together with the unsuitable nature of the earth used in filling in the basement.

The old flooring of the Cavalry cistern was composed of 6 inches of concrete laid upon the made earth with which the basement of the cistern was filled in. On the concrete was laid a flooring of stone set in mortar, and pointed with asphalte. On examination it was found that the new floor of two course of brick-on-edge laid in cement diagonally and plastered had sunk in several places, owing to the subsidence of the made earth under pressure. The water passing through the cracks in the new floor at these places had increased the evil, by reducing the earth in the basement to a state of pulp.

The same description applied to the floor of the filter where the sinking took place at the point where there was the greatest depth of made earth. It may be observed that the filter is built on the bund of the tank, which circumstance doubtless added to the possibility of failure. Upon the report of this failure Government decided that the capacity for storage was not required to be so great as when the cisterns were first designed, and that the second half of the Race Course barracks cistern should be left as it was, but that measures must be taken to repair the filter.

Third revision of Project—Dhobies' Wells.—Up to 31st March, 1869, the total expenditure on the project was Rs. 1,55,665, and in May of that year a revised estimate was submitted by Captain Wood, R.E., for Rs. 2,65,000 for completing the scheme on the modified arrangements already noted, and with a further modification on Lieut. Pennycuick's project by the substitution of stand-cocks at convenient positions for house supply in place of the detailed distribution to individual quarters. This estimate provided for a supply of water from the Ulsoor Tank for ablutionary and non-culinary purposes only, as in July 1868 it had been decided that even after filtration the water from the Ulsoor tank was unfit for drinking.

At the time when this revised estimate was submitted, the condition of the work was as follows :—

Engine erected, filters, fresh water basin and cisterns complete, except that for the Parade barracks. Main lines of piping laid to cisterns and east gate of European Infantry barracks, and distributing pipes to Royal Horse Artillery and Race Course barracks. To complete the work, it was required to add verandah to engine house, enlarge quarters, complete main to Parade barrack cisterns, and to complete the distributing arrangements.

With this estimate were also forwarded designs for floating covers to the cisterns and pure water basin. This was considered necessary to preserve the water from pollution by bones and impurities dropped in by vultures and other birds, as well as to preserve it from vegetable growths induced by exposure to the direct action of the sun. These covers consisted of corrugated iron sheeting carried on timber purlins 4″ × 4″ at 5 feet interval, supported on square buoys 2′ × 2′ × 2′ of $\frac{1}{16}$ sheet iron, strengthened and put together with angle irons, and placed at 9 feet central interval. They, however, were not sanctioned.

Owing to the unfavourable reports upon the tank water in July 1868, Government purchased the Dhobies' wells for the purpose of supplying the troops with pure water for drinking and culinary purposes, and directed the preparation of estimates for a scheme for pumping water from these wells to the barracks.

To the east of the tank, about 300 yards north of the rock and 30 yards in rear of the bund, were a number of wells, originally seven, situated in what was called the new Dhobies' ground.

These wells appeared to be fed by percolation from the tank through the bund, which takes place more or less along the whole line of bank on the south-east from the waste weir towards the north. The percolation is moderate towards the south-west part, where the soil is clay or disaggregated gneiss, but abundant at the north-east end, where a triangular bed of ferruginous gravel about 200 yards wide allows the water to filter very freely. The line of demarcation of this gravel bed is well defined. It extends well into the new Dhobies' ground, and the water in the wells stands at 5 or 10 feet from the surface according to the ground in which they are sunk being within or without the gravel bed.

All over this gravelly patch of ground water stands at a level of about 6 feet below the surface of the water in the tank, falling regularly with it.

Observations for 18 weeks, from 1st January to 29th April 1871, showed that the fall of water in the wells was nearly always identical with the amount of fall in the tank, the fall in the wells being, as a rule, about one inch more, and the difference never more than two inches.

The water derived from these wells was excellent, but on this point more will be said hereafter, and it is sufficient now to state that at this period of the work it was considered to be fit for drinking and culinary purposes.

In June 1869 plans and estimates were submitted for three projects for supplying the troops with water from these wells for drinking and culinary purposes.

In place of a single reservoir in the water-bearing stratum from which to draw the supply, it was decided to increase the area of the wells by sinking a number of separate wells, and connecting them by masonry driftways, by which a number of small reservoirs would be obtained, which could at a moderate cost be covered in, so as to preserve the water from the action of the rays of the sun.

The estimates provided for increasing the number of wells to 16.

In Project A it was proposed to draw the water from the wells, and pump it up to a stand pipe on the Ulsoor rock, whence it would descend to the cisterns at the barracks.

In Project B it was proposed to pump the water into an iron cistern constructed on the top of the rock, capable of containing the whole supply for the barracks.

In Project C it was proposed to pump the water into a stand pipe at the site of the Dhobies' wells, and thence to cisterns at the barracks.

The object of this scheme was, as before stated, solely to supply the troops with drinking water, and it was to be kept entirely distinct from the Ulsoor rock arrangements.

The demand for culinary purposes was estimated at 5 gallons per head per diem, and the number of souls to be supplied was estimated at—

Cavalry and Artillery at Race Course barracks,... ...	1,200
Royal Horse Artillery, ...	250
Infantry, ...	1,200
Total, ...	2,650

requiring for drinking a daily supply of 13,250, or say 100,000 gallons per week, which would be distributed to the barracks in the proportion 45,000 gallons to the Cavalry and Infantry barracks, and 10,000 to the Royal Horse Artillery. This required a discharge of 90 gallons per minute at the latter barracks.

The dimensions of the pipes were calculated by Neville's formula, and assuming the stand pipes to be constructed so as to give a head of 20 feet above the highest point to be supplied, viz., the Infantry barracks cistern, it was found that a $4\frac{1}{2}$-inch pipe was required in all cases except for the Royal Horse Artillery cisterns, where a $2\frac{1}{2}$-inch pipe was sufficient in projects A and C. In project B 3″ × $1\frac{3}{4}$″ piping was found sufficient.

The cisterns were to be of wrought-iron, those at barracks being raised 20 feet above the ground on cast-iron pillars, and the single cistern at the rock to be 42 feet above the top of the rock. The objection to the project of the single cistern at the top of the rock in place of separate service cisterns at the barracks was, that the whole of the water would have to be raised 40 feet above the rock, while it was only necessary that the quantity required by the European Infantry, viz., 45,000 gallons, should be so raised. The advantage of this arrangement would have been the possibility of a more economical distribution of the water, as the amount to be delivered could have been regulated carefully and waste checked.

In projects A and C stand pipes were provided, in the former case on the rock, in the latter case at the Dhobies' wells. With a stand pipe at the rock, which would have to be 42 feet high, there would be loss of power, water having to be delivered at the stand pipe at the distance of 1,800 feet from the engine house at the Dhobies' wells. A stand pipe at the Dhobies' wells would have to be at least 100 feet high to obtain the required command, and the difficulty of erecting and maintaining such a pipe would probably be of greater consequence than the loss of power experienced in the other case.

The minor distribution in all three projects was practically the same, viz., by stand cocks or water houses at suitable points in the barracks.

The cost of the three projects was nearly the same, viz.—

	Rs.
For A, ...	1,34,700
„ B, ...	1,33,000
„ C, ...	1,36,500

No provision was made for supply to the old Foot Artillery cistern, as the old Foot Artillery barracks were abandoned about this time, and a supply there not required.

The work in connection with the Ulsoor rock project was sufficiently advanced to allow of the Royal Horse Artillery and Race Course barracks being supplied from them with water for ablutionary and non-culinary purposes from January 1871.

The projects when first received by Government were laid aside in consequence of the magnitude of the estimates, and the state of the Imperial finances. An engine and pumps were, however, despatched to Bangalore, and an entry made in the Budget, and accordingly 16 new wells were sunk and connected, and the engine house and chimney built. The work being so far advanced, in G. O. 1278 of 18th May, 1870, Government directed that the work should be carried out as simply as possible, to provide for a supply for two days consumption of drinking water.

In September 1870 the Superintending Engineer proposed to connect the Dhobies' wells with the existing piping of the Ulsoor rock project, and to pump into the cisterns to test the yield of the wells. Government objected to any arrangement by which the water from the wells could be exposed to contamination with that from the tank, and in December 1870 as ordered, a revised scheme, differing only in minor details of distribution and in fixing the supply at 3 gallons per head from that sent in June 1869, was submitted. It provided for carrying out the arrangements for completing the supply of water for non-culinary purposes from the Ulsoor rock scheme, and for a separate service for drinking water from the Dhobies' wells.

Result of working of Ulsoor Project.—During the period that the water from the Ulsoor project had been in use, it was found that an average of 30,000 gallons per day had been used by

Horses, ...	780
Troops and families, ...	1,300
Native followers, ...	2,150
	4,230

being an average of about 7 gallons per head. But assuming 12 gallons per day expended on each horse, there remained about 21,000 gallons left as expended by the troops and their followers, and supposing the latter to use 1 gallon a day, the consumption by the troops would be 14 gallons per head.

The cistern at the Infantry barracks was designed on this data to contain about 7 days' supply. Owing to the unsuitability of the levels of the ground, the cistern had to be built in the Bakery square at the western end of the Parade barracks, which involved an extra expense of Rs. 6,950 for piping, which would otherwise have been spared.

Amalgamation of the two schemes.—The two schemes were now amalgamated under one head, and the total cost of the combined scheme came to Rs. 3,07,400, for which the troops and horses were to be supplied with 14 gallons per head for non-culinary purposes from the Ulsoor tank, and 3 gallons per head for drinking from the Dhobies' wells. The latter allowance could be increased if the wells were found equal to the strain.

Suggestions by Sanitary Commissioner.—In May 1871 the Sanitary Commissioner, after visiting Bangalore and inspecting the water supply, suggested the possibility of the Dhobies' wells being able to meet the demand for all requirements both for ablutionary and non-culinary purposes. Should this prove to be the case, he further suggested the probability of Government being able to dispose of the water works and plant of the Ulsoor project to the Municipality.

Experiments on capacity of Dhobies' Wells.—Acting on this suggestion in May 1871, the yield of the wells was ordered to be tested, and pumping experiments were carried out from 20th to 26th May. It had been ascertained that not more than 35,000 gallons daily is used by the troops, and the actual amount pumped out during the six days was 330,000 gallons, or about 116,000 gallons in excess of what the troops would have consumed in the same time. At the end of the sixth day, however, the wells were nearly drained dry, only 2⅝ feet of water remaining in them. It was found during the experiment that a considerable quantity of water filtered into the wells while pumping was going on. The experiment showed conclusively that the capacity of the present number of wells was amply in excess of the requirements for culinary purposes only. Also the least amount filtered in daily during pumping was 17,000 gallons, and during the night 8,000, a total of 25,000 gallons per day, or 10,000 gallons less than the assumed expenditure of 35,000 gallons. The wet perimeter of the 16 wells was about 500 feet, and therefore to allow of 35,000 gallons being filtered in daily, the perimeter should be $5{,}000 \times \frac{35{,}000}{17{,}000} = 1{,}000$ about, or the number of wells should be doubled. A table of the detail of the experiment is attached, which will explain the results better than any description.

By G. O. 1933, dated 22nd July, 1879, Government directed the submission of two estimates, one for the completion of the supply from the tank, and one for completing arrangements for supply entirely from Dhobies' wells, to include 16 additional wells and new steam engine and pumps.

Conclusions arrived at after careful analysis of the tank and well water.—The analysis of the tank water made in 1871 has already been referred to in page 6. The result of the comparison then made between the waters of the tank and wells may now be given.

The water from the Dhobies' wells is almost identical with the tank water after filtration. It differs only by having a little less calcium carbonate and *organic* matter, and a little more silica and magnesia. The fact of its containing less organic matter renders it preferable for drinking purposes. The waters of the Ulsoor tank (filtered) and of the Dhobies' wells were compared with the standards laid down by Dr. Parkes, *1st*, for pure and wholesome; *2nd*, for usable drinking water. It was found that the tank water after filtration was equal to the second standard in every respect, and to the highest standard in all but three points. When further subjected to domestic filtration, the water from the Dhobies' wells comes up to the highest standard, and the Ulsoor tank water fails only in one point, viz., the larger amount of oxygen consuming organic matter, a defect common to all tank waters. Both waters exceed the highest standard on several important points, so that the sources of supply are exceptionally good.

In G. O. 528 of 26th February, 1872, the opinion of the Sanitary Commissioner upon the data deduced from the analysis is that, although under ordinary circumstances the water of the Ulsoor tank when filtered is perfectly pure and wholesome, and may be safely issued for the use of the troops, that the Dhobies' well water, owing to its freedom from all organic matter, is the safest and best.

Accordingly Government sanctioned the completion of both schemes, in order that they might mutually assist each other, the water from either source being transmitted by the same lines of piping to the same reservoirs.

The final revised scheme.—In anticipation of the same line of piping being available for either source, estimates for completing the two schemes had been submitted in November 1871 as ordered in the G. O. of June 1871.

To complete the Ulsoor project, all that was required was to continue the main to the east gate of the Infantry barracks to the cistern in the

Commissariat square, and carrying out the minor distribution which would practically complete the original scheme submitted in May 1869.

A further modification on this scheme was made by the provision of iron cisterns in the upper stories of the male and female hospital at the Agram barracks, so as to furnish the hospitals with a distinct house service.

It was at first intended that the iron cisterns in these hospitals were to be filled by a moveable steam engine at the hospitals. This, however, was found not to be required, as a sufficient command was obtained by the stand pipe on the rock. The cisterns were supported on cast-iron pillars resting directly on the ground, the weight being in no way carried by the walls of the building. The cisterns in the male hospital are each 22′ × 14′ × 2½′, those in the female hospital 10′ × 10′ × 2½′.

To complete the Dhobies' wells scheme in addition to the above works, 18 more wells had to be sunk, and a main laid on from the engine house to the sweet water basin at the rock. The Dhobies' wells scheme was the costlier by Rs. 22,400.

No provision was made for repairing the ruptured filter at the rock, and the useless half cistern at the Agram barracks.

The total amount required to complete the two projects was Rs. 3,01,698.

In the project provision was made for 15 gallons per head per day, or 36,000 gallons, but the Executive Engineer expressed his opinion, from the average consumption observed that, 10 gallons per head, and 8 gallons per horse per day, was probably enough.

In April 1872 the Government of India sanctioned the above estimates, remarking at the same time that either project singly would have sufficed for the supply of the Cantonment, but both projects being so far advanced, both must be completed.

As a spare filter was evidently required, the repair of the ruptured filter was also strongly urged by the Government of India.

Progress of the combined scheme.—As soon as sanction was obtained the extra wells were commenced. The wells were 20 feet deep, with a lower diameter of 9½ feet, and upper of 10 feet each, for a height of 10 feet, lined with a loose stone backing of small stone, the mouths being closed by a granite slab square of 15 feet, with an opening of 3 feet left with a stone cover supported on two granite stones 15′ × 1′ × 1½′.

The wells were connected with each other, and with the old wells by horizontal driftways formed of stone. The floors were 4 inches above the bottoms of the wells, the side stones 2½ feet high and 1½ feet thick, floors of slab stones 4′ × 1′ × ½′, and covered by slab stones 4′ × 1′ × ½′ (see *Plate* I.)

In carrying out the work, the excavation for the wells was carried down to the full depth before the lining was commenced.

In addition to the extra 18 wells sanctioned, it was at one time proposed to sink 5 additional wells, and these were actually begun. They were, however, objected to by the Local authorities on the grounds that they endangered the safety of the bund, as they were sunk close to the rear slope. They were ultimately abandoned and filled in.

In 1874-75 the works connected with Ulsoor Water Work Project were completed.

Action taken with regard to the filter at the rock.—In September 1872 an estimate amounting to Rs. 3,490 was prepared for repairing the filter, which provided for picking up the flooring all round inside the walls for a width of 10 feet, excavating for a depth of 7½ feet, filling in with a concrete lining backed by puddled clay, and replacing the flooring carefully by two courses of brick in cement. Before this was carried out, the condition of the cistern became worse, and it was decided to take up the whole of the flooring, and relay it with brick in cement 9 inches over concrete, 9 inches above a well rammed layer, 18 inches deep of laterite gravel. An estimate for such repairs was accordingly submitted, and repairs on this plan executed in May 1873.

Previous to the work being sanctioned, excavation had been carried inside and along the walls for the concrete lining, which was, however, not put in, puddled clay being used to fill in the excavation.

The new floor was laid as above detailed, and in addition an inside lining wall of brick in mud was constructed along the walls and plastered with cement, and the filtering material placed on the floor.

The filter was then filled, but it was found to leak as badly as ever. The wall near the road yielded, and was thrown slightly outwards, more so at the corner abutting on the road and farthest from the tank. Here too the side wall was ruptured, showing that there had been subsidence at this corner, which had torn the masonry away from the other portion. There are no working plans in existence showing the dimensions of the walls as actually constructed.

The excavations behind the walls revealed the fact that the lower courses of the masonry in the foundations were set in mud not mortar.

It was considered that leakage was due not to subsidence of the floor but to failure in the lower wall, and it was decided to be necessary to rebuild the walls in a thoroughly sound manner. Before proceeding to estimate for the entire re-construction of the walls, a very thorough examination of the site was made, the nature of which will be understood by a reference to plan of filter, *Plate* IV. Excavations were carried down at A, B, C, D and E, and in the first two cases rock was met with at a depth of 3 feet 5 inches and 2 feet 8 inches respectively below the floor, but at C, D, E no rock was found at depths of 26½, 28⅝ and 26½. A shaft was then sunk at E, and below floor level the wall was found to consist of 1¾ feet brick in chunam, 3¾ feet stone in chunam, and below this again 4½ feet of rock in earth, altogether the wall was 10 feet high below floor level. At the bottom of this shaft an iron rod was forced down for a further depth of 15 feet, but no rock was met with.

A portion of the floor was next removed just inside the wall, and after excavating for a depth of 15½ feet, an iron rod was forced down for a further depth of 5½ feet without rock being reached. Thus along the whole length of the wall by the roadside, rock cannot be found at depths varying from 25¼ to 28⅝ below the floor, and a section of the filter and road embankment show that the floor is 18·43 feet above the ground, and 26·67 feet above the excavation made for the embankment at the time of forming the road. *See Fig.* 6.

The following information was also obtained regarding the condition of the site previous to the construction of the filter.

The original bund of the tank passed between the present filter and the pure water basin to the rock. Some little time before the filters were built, the road round the rock was formed; its crest being about 18½ feet above the ground, and previous to this the ground between the old bund and the new road embankment was a marsh full of reeds. Shortly after the road was formed, the space between the two banks was selected as a suitable site for the filter. A good deal of rock had to be blasted on the site of the upper filter, and this *débris*, together with rock obtained from the surface of the rock, was used to fill in the marsh on the site of the lower filter. When this made earth, rock, &c., was brought up to what was considered a sufficient level, boulders in clay were built on it as a foundation for the wall, on this stone in chunam, and above this brick in chunam to the level of the floor.

This being the method of preparing the site and building the wall, it is not surprising that the work failed. It is also probable that the site being built upon so soon after the construction of the road embankment, settlement occurred in the latter, and affected the site with the result of the failure of the walls.

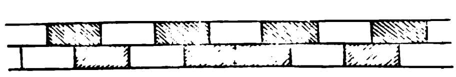
The masonry found in the walls was of fair quality, and the failure cannot be attributed to bad workmanship, but to a mistaken design.

Under the circumstances thus brought to light, it was evident that the work required to re-construct the wall of the filter upon a solid foundation would be very costly, in fact it was roughly estimated to fall not far short of Rs. 40,000. Accordingly in January 1876 Government decided that the repair of this portion of the filter must be abandoned, but as it was necessary that a second filter should be provided to allow of the one then existing to be cleaned or the filtering material changed, it was determined to build a second filter on a fresh site.

No ground was available near the original filter on the rock, but a site was selected near the engine house attached to the Dhobies' wells. The ground here being below the level of the water in the Ulsoor tank, a supply could be drawn thence by a syphon, and led on to the filter when required, and pumped thence by the Dhobies' wells engine to the pure water basin at the Ulsoor rock for distribution to the barracks.

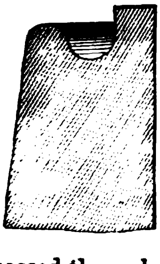
Estimates for these works were acccordingly framed and sanctioned in 1877-78.

Working of the Ulsoor filter.—Previous to designing a new filter, the action of the one already working at the Ulsoor rock was tested. The surface area of the filter at the rock is 5,842 square feet. The depth and composition of the filtering material is as follows:—On the bottom of the filter are placed stone slabs 3 inches thick of different sizes varying from 2 to 4 square feet, placed so as to form conduits thus, the stone is then



brought up to a depth of 1 foot by small slab stones. On this is a large stone jelly 1 foot in depth, capable of being passed through a 2½ inch ring, above this 8 inches of small quarry sweepings covered by 4 inches of charcoal (vegetable), on which rests a layer of 2½ feet of rather fine Bangalore sand.

The water from the tank is pumped into a trough running along the top of one wall for the whole width of the filter, which allows the water to pass quietly over a smooth curved edge into the filter as shown in sketch. Vertical iron pipes are erected to allow the air from below to escape, and prevent its disturbing the sand while it is being filled.



The following is the method of collecting the water and conveying it to the pure water basin after it has passed through the filtering material. The floor of the filter slopes gently to the corner whence it is to be discharged. The water falls through the filtering strata to the stone conduits placed on the floor, and from thence passes to an arched brick conduit, built along that side of the filter which contains the outlet to the pure water basin. The maximum head of water on the filtering material is 3 to 3½ feet. The quantity of water filtered was carefully gauged from 7 A.M. September 15th 1875, to 7 A.M. on 16th idem, when it was found that 48,000 gallons had been filtered in 24 hours. The filtration took place under most favourable circumstances, as the day before trial the sand was scraped and dug up to a depth of 18 inches, and moreover the filter having been in use for some time, the depth of the layer of sand had been reduced some 7 inches by repeated scrapings. During the trial the head of water varied from 3 feet 7 inches to 2 feet 3 inches. Thus under the most favourable circumstances the filter cannot purify more than $\frac{48{,}000}{5{,}842} = 8{\cdot}216$ gallons per square foot in 24 hours. Directly the discharge into the pure water basin shows signs of imperfect filtration it is checked by a valve.

Additions to the Ulsoor Water Works.—In 1876-77 the old engine at the Dhobies' wells was removed, and replaced by a new compound horizontal engine of 10 horse-power, pumping on an average 13,400 gallons per hour = 223 gallons per minute.

In 1877-78 an estimate of Rs. 66,598 was sanctioned for additions to the Ulsoor water works, which provided for iron roofs to the cisterns and pure water basin, fixing the new engine and pumps at the Dhobies' filter, and providing the additional filter. These works, together with a pure water basin, have been completed, and nothing further remains to be done to the work except to roof two of the cisterns.

The filter and pure water basin at the Dhobies' wells.—When the plans for the new filter with the arrangements for distributing the water in connection with it were first drawn up, it was intended that the filtered water from the filter should be conducted to the pumping well direct, and thence pumped to the pure water basin at the rock.

This plan was objected to by Major A. D. C. Scott, R.E., the Deputy Chief Engineer for Irrigation, on the grounds that as the pump well is connected with the system of wells, if the filtered water were allowed to pass into it, it would diffuse itself through the system of wells without materially raising the level of the water in the pump well in which the suction pipe works.

He directed that a small pure water tank of about one-quarter the capacity of the filter should be constructed near it, to which the filtered water should pass, and that when using Ulsoor tank filtered water the engine should pump direct from this pure water tank and not from the pump well. The yield of the filter being 40,000 gallons, or one day's supply, that of the pure water tank was to be 10,000 gallons.

The Engineer in charge of the works believed that this diffusion would not take place to so large an extent, as the laterite strata in which the wells are sunk is surrounded by a bed of stiff clay, and the pumps would draw from the whole bed of water.

The pure water tank being of so small a capacity, would be emptied by the pumps in about half an hour, and the engine would then have to stop working or draw from the wells until the pure water tank filled again. The Engineer contends that this spasmodic mode of working the engine would be costly and injurious to the machinery. Colonel Moberly R.E., lately in charge of the Division, proposed to overcome the difficulty by having a double branch from the suction pipe in the pumping well provided with valves, so that upon the tank becoming empty, the engine could be turned on to the supply from the Dhobies' wells without stopping until the tank had filled again.

Revised plans and estimates for the filter and a pure water tank were submitted, which can be understood by a reference to the *Plates*. The arrangement and depth of filtering strata were similar to that adopted in the filter at the rock, but the construction of the flooring was very different, the floor consisting of 2½ feet of puddled clay laid in layers 6 inches thick, next a layer of stone metal 8 inches thick set in clay well rammed, and above this 4 inches of concrete laid in furrows and ridges, the furrows leading along the short width of the filter. In the furrows stone drains were laid, packed with loose stone, over which was laid the filtering strata, *see Plate* III.

The water flows into the filter from a trough along the top of one wall, as in the one at the Ulsoor rock, but instead of being lead as there into an arched chamber after filtration, the stone drains conduct it to a perforated iron pipe laid along the foot of the wall, which leads the water to the outlet pipe into the pure water basin.

The filter has not been carried out exactly according to the plan. The concrete sloping walls were found to bulge, and they were covered with a casing of brick in chunam in steps.

On testing the filter it was found to leak very considerably, and the irregularities of the faces of the inner walls were filled in with concrete, and the whole plastered with surki and Portland cement. I regret to say that the filter leaks still, though to not nearly the extent previously. Leakage here is not of great consequence, as the filter is filled from the tank by gravitation, and what water does escape probably finds its way to the wells close by.

The scheme as complete.—The works are now complete in all their details, and it remains to enquire into their working, and their capabilities as to their supply compared with the requirements of the garrison.

The existing system of water supply for the European troops at Bangalore may be briefly described thus—

I. *Source of supply.*—The Ulsoor tank and Dhobies' wells situated about one mile from the most distant barrack to be supplied.

II. *Head works.*—Engine house and 12 horse-power engine and pumps, filter, pure water basin and stand pipe, quarters for the Engineer in charge at the Ulsoor rock; engine house, 10 horse-power engine and pumps, 32 wells, small pure water basin and filter at the Dhobies' wells.

III. *Distributing arrangements.*—12,208 feet of cast-iron main pipes, of diameter ranging from 10 inches to 4 inches. Single masonry cisterns at the Cavalry and European barracks.

A double masonry cistern at the Royal Horse Artillery barracks.

Four wrought-iron cisterns in the hospitals at the Cavalry barracks.

35,461 feet of cast-iron distributing pipes, ranging from 7 inches to ½ inch diameter.

49 Stand cocks.

IV. *Population to be supplied*—

	Men.	Women.	Children.	Native followers.	Horses.
1 Battery Royal Horse Artillery,...	157	24	27	317	178
1 Regiment Cavalry, ...	455	56	142	567	436
2 Batteries Royal Artillery, ...	314	43	74	418	220
1 Regiment Infantry, ...	886	104	178	...	...
Totals, ...	2,460			1,302	834

V. *Demand*—

14 Gallons per day per European.
1 Gallon „ Native.
12 Gallons „ Horse.

Therefore—

Royal Horse Artillery	require	5,493	gallons per day.
Royal Artillery	„	9,078	„
Cavalry	„	14,941	„
Infantry,	„	16,352	„
	Total, ...	45,864 = 46,000 gallons, say.	

The supply is drawn from the Dhobies' wells by preference, is pumped by the engine there to the pure water basin at the rock, whence the engine at the rock pumps it to the cisterns at the barracks.

If the supply in the Dhobies' wells fails, which it generally does during the hot months when the tank is low, the supply is drawn from the tank and pumped into the filter at the rock, whence it gravitates into the pure water basin, to be pumped up by the engine to the stand pipe, and thence to the cisterns at the barracks.

If the filter at the rock is out of order or requires cleaning at a time when the full supply cannot be drawn from the Dhobies' wells, the tank water can be allowed to flow by gravitation into the filter at the Dhobies' wells, and on to the small pure water tank there, whence the Dhobies' wells engine pumps it up to the pure water basin at the rock, to be sent on as before by the engine there.

The actual capacities of the several filters and reservoirs are as follows:—

Filters.—

	Gallons.
The filter at the rock can purify per day	37,971
That at the Dhobies' wells	32,500
The pure water basin contains	149,425
Royal Horse Artillery cistern contains	179,025
Cavalry barrack cistern contains	280,087
Infantry „ „ in Bakery square	112,500

Comparing these figures with the statement of probable demand given above, it will be seen that the capabilities of the works are as follows:—

The filters can purify	1¼ days' supply for the garrison.
The pure water basin holds ...	3·2 „ „
The R. H. Artillery cistern holds ...	32 6 days' supply for the R. H. Artillery.
The Cavalry barrack cistern holds...	12·1 days' supply for one Regiment Cavalry and 2 Batteries Royal Artillery.
The cistern in the Bakery square,...	6·8 days' supply for one Regt. Infantry.

It may be noticed that the cistern in the Bakery square has to meet demands not only for supply to the Infantry, but also to the Bakery and Commissariat buildings, the requirements of which cannot be correctly ascertained. It would not, however, be very great.

The following is a description of the engines.

The one at the rock cost £2,000 in England, and is a Watt's double acting beam condensing low pressure engine of 12 horse-power nominal, with a piston area of 254·5 square inches, and length of stroke of 22 inches, driving three force pumps with cylinders 1 foot in diameter, and plungers of 2 feet stroke, capable of raising 410 gallons per minute. The average rate of pumping is 300 gallons per minute.

The engine at the Dhobies' wells cost £1,138 in England, and is a direct, double-acting, compound horizontal condensing engine of 10 horse-power nominal, working under high and low pressure; area of high pressure piston 53·5 square inches, and of low pressure piston 188·7 square inches, length of stroke 12 inches, driving three force pumps with cylinders of 10 inches diameter, and length of stroke of plungers 18 inches, capable of raising 238 gallons per minute, the average rate being 223 gallons per minute. Both engines work expansively. The boilers are cylindrical, thickness of plate $\frac{7}{16}$-inch, that at the Ulsoor rock being 12 feet long, 4 feet 8 inches diameter, with 22½ inches fire grate surface, and that at the Dhobies' wells being 12′ × 5′ 1″ diameter, with 14½ inches of fire grate surface.

Both engines burn wood.

The following are data deduced from observation of the working of the two engines.

On 15th September the Ulsoor rock engine pumped up 128,565 gallons from the pure water basin to the Cavalry barrack cistern in 5 hours 13 minutes, a rate of 410·75 gallons per minute, and burnt 2,355 lbs. of wood. On the same day, the same quantity was pumped up by the Dhobies' wells engine to the pure water basin in 9 hours, a rate of 238·0 gallons per minute, with an expenditure of 3,874 lbs. of fuel.

The lifts are as follows :—

From wells to pure water basin, 36·25 feet.

From pure water basin to top of stand pipe, 78·00 feet.

The nominal horse-power to accomplish this would have been in the rock engine $\frac{410{\cdot}75 \times 78 \times 10}{33{,}000} = 9{\cdot}10$, or adding 50 per cent. $= 13{\cdot}6$ horse-power, and in the wells engine $\frac{238{\cdot}08 \times 36{\cdot}25 \times 10}{33{,}000} = 2{\cdot}7$, or adding 50 per cent., 4·05 horse-power.

In the rock engine the indicated pressure was 20 lbs. per square inch, and the number of strokes per minute 45, so that the indicated horse-power was $\frac{2\,A,\,P,\,R,\,S,}{33{,}000}$, where $A =$ area of piston, $P =$ pressure per square inch, $R =$ number of strokes per minute, and $S =$ length of stroke in feet $= \frac{2 \times 254{\cdot}5 \times 45 \times 22}{33{,}000 \times 12} = 25{\cdot}5$ horse-power, or more than double the nominal horse-power of the engine.

In the Dhobies' wells engine the steam was working at 50 lbs. pressure, and the number of strokes per minute was 40, so that the actual horse-power was $\frac{2 \times 53{\cdot}5 \times 40 \times 50 \times 1}{33{,}000} = 6{\cdot}5$ horse-power.

The expenditure of fuel in the rock engine was 230·5 lbs. per hour, producing an indicated horse-power of 25·5, while the indicated horse-power in the Dhobies' well engine being 6·5, the consumption of coal was 430 lbs. per hour. From this it would seem that the engine at the Dhobies' wells is very costly as regards fuel, but the above calculations are rough only, it is very probable that I have under-estimated the actual horse-power of the wells engine. The main from the Dhobies' wells to the pure water basin is small, only 5 inches diameter, and considerable additional power is probably required to drive the water through this small piping, and, moreover, there are no indicator diagrams kept, so that it is impossible to know exactly how the steam is working in the cylinders.

Supposing it were ever wished to pump the water from the wells straight up to the barracks, I am inclined to think that the Dhobies' wells engine would be sufficiently powerful to accomplish it, but it would be necessary to replace the small 5 inch main by a 10 inch main connected with the main from the stand pipe at the Ulsoor rock.

The top of the stand pipe on the rock is 107 feet above the low water mark of the wells, and the engine would have to force the water through the pipes with a pressure equivalent to this lift.

Supposing the engine to pump at a slower rate of 200 gallons per minute, in which case it would raise 96,000 gallons, or two days' supply in 8 hours, the nominal horse-power required would be $\frac{200 \times 10{\cdot}7 \times 10}{33{,}000}$ $= 6\frac{1}{2}$, or adding 50 per cent. $= 9{\cdot}75$, or 10 horse-power the present nominal horse-power of the engine.

Pumping with a single engine would effect a saving in fuel.

In place of a stand pipe at the Dhobies' wells the main from the engine is provided with a spring valve adjusted to support a pressure up to 50 lbs. on the square inch, equivalent to a head of water of 115·47 feet.

From the returns of the working of the system for the last official year, the following is obtained:—

Quantity of water pumped up daily (average), ...	43,460 gallons.
" " filtered, ...	11,665 "
" fuel expended daily, ...	3,837 lbs.

	RS.	A.	P.
Monthly cost of fuel, ...	377	0	0
" " establishment, ...	506	0	0
" " repairs, ...	12	4	0
Total, ...	895	4	0

Say Rs. 900.

In last official year the total quantity of water pumped up from the wells was 14,419,800 gallons, equal to $\frac{14{,}419{,}800}{32} = 450{,}620$ gallons per well. The total quantity pumped up to the barracks was 15,863,858 gallons, so that only 1,444,058 gallons had to be drawn from the Ulsoor tank.

It may be noted that had the 5 wells commenced and abandoned in 1876 been completed, an additional yield of 450,620 × 5 = 2,253,100 gallons might have been expected, in which case the entire supply could have been obtained from the Dhobies' wells. It must, however, be remembered that during 1878-79 the garrison was under its full strength.

Cost of the work.—It is not possible to give a correct statement of the cost of the project in detail. As will have been seen from what has been already stated, a good deal of work has been done that was ultimately abandoned, and no account has been kept of the various works under separate heads. In addition to this expenditure, an account of conservancy and repairs has been mixed up with the accounts of the work, together with cost of stores received from England, and after all not required, while a good deal of the work in connection with the Dhobies' wells scheme was carried out before the estimates were prepared.

The amount originally sanctioned in 1862-63 was Rs. 72,000. This was several times increased, as has been already noticed, and in 1871-72 the cost of the Dhobies' wells scheme, which had sprung into existence in the interval, was amalgamated with the Ulsoor rock scheme, and the whole amount sanctioned for the completion of the two schemes was Rs. 3,01,698. Of this Rs. 2,77,347-2-1 has been spent up to 1875. In 1877-78 an estimate for Rs. 66,598 was sanctioned for additions to the water works, which was made up as follows :—

	Rs.
Iron roof to pure water basin, ...	6,700
" " Agram cistern, ...	16,520
" " Royal Horse Artillery cistern, ...	10,450
" " Bakery cistern, ...	4,230
Additional filter with piping, ...	12,600
Fixing new engine and pump at Dhobies' wells, ...	16,098
Total, ...	66,598

Of this Rs. 23,245-6-1 has been spent up to date.

To recapitulate—

	Rs.
Total amount sanctioned, ...	3,68,296
" " spent, ...	3,00,592
Balance unspent, ...	67,704

Remaining to complete—

	Rs.	
Iron roof to Agram cistern, ...	16,520	... 26,970
" Royal Horse Artillery cistern,...	10,450	
Probable balance on final completion, ...		40,734

From what records I can find, I estimate the cost of some portions of the work as follows:—

			Rs.
1.	*Cisterns* at Cavalry barracks,	... ...	9,500
2.	" Royal Horse Artillery, ...	... ...	3,800
3.	" Royal Artillery (abandoned),	... ...	2,720
4.	" Bakery square, ...	... ...	5,820
5.	Two iron cisterns (small), ...	... ...	2,500
6.	Two " (large), ...	... ...	10,740
7.	Pure water basin, ...	... ...	6,351
8.	New filter,	... ...	7,755
9.	Sinking and connecting the wells, ...	... ...	13,300
10.	Purchase of ground,	... ...	2,342
11.	Engine house at wells,	... ...	8,000
12.	Chimney 80 feet, ...	... ...	2,560
13.	Engine driver's quarters, ...	... ...	2,430
14.	Stand pipe,	... ...	345
15.	Piping, ...	... ...	97,537
16.	(49) Stand cocks, each,	... ...	35
17.	Iron roof to pure water basin,	... ...	6,351
18.	" cistern, Bakery square, ...	... ...	4,006
19.	Repairs at various times, ...	... ...	10,872

Beyond these items I can give no other detail of expenditure, the above are given here as they might form a rough guide hereafter in approximating the cost of somewhat similar schemes to be undertaken elsewhere.

General Remarks.—It will be seen that the scheme as carried out falls short of the objects proposed to be secured in Lieut. Tulloch's original project in more than one particular.

1. The supply of pure water that the two filters can yield in 24 hours is not more than 70,471 gallons, or not two days' supply, while as originally intended, the main filter was to have supplied three or four times an estimated daily draft of 60,000 gallons.

2. With the exception of the Royal Horse Artillery cistern, none of the other reservoirs are capable of storing a month's supply, and supposing any serious accident to happen to the machinery or pure water basin, the supply for the Infantry would probably be exhausted before the system could be brought into working order again.

3. Settling beds have not been provided; to this fact, I think the slow filtration may be attributed. The tank water contains a very large quantity of suspended matter. The appearance of the filter when empty shows

that the surface of the sand stratum is thickly caked with clay, a circumstance that must after a time tend to retard the descent of the water through the filtering media, besides necessitating frequent scraping and partial removal of the sand.

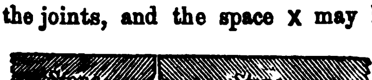
It will be observed that there is only one pure water basin capable of holding little more than three days' supply, and that the uninterrupted supply both from the tank and from the Dhobies' wells is entirely dependant upon the integrity of this reservoir. Great stress was laid upon the importance of having a second filter in case one should require repair, and it seems to me that the necessity of a reserve pure water basin is equally important. In fact I am of opinion that this is of greater importance, for whereas a filter is a link in the Ulsoor rock scheme alone, which in no way affects the system of supply from the Dhobies' wells, the pure water basin forms a most important link in the two schemes, any failure in which would paralyze the action of either system unless arrangements are made to pump from the wells direct. A site for a second pure water basin could be found on the north of the rock near the boat house.

I would also notice what appears to me a serious point in the character of the water supply. Regarded as a system of supply to a town, it is doubtless ample for all its present requirements, and with the enormous capacity of the main source of supply, the Ulsoor tank could be extended to meet much larger demands. But as a Military source of supply it is open to the serious defect of insecurity. The water works, the fountain head of the supply, are situated at a distance from the barracks, are in no way defended, and in the event of an outbreak, a small expenditure of time and gunpowder would suffice to inflict such damage to the machinery as would stop the water supply entirely for very many months, while with a little skill the whole scheme might be so effectually damaged as to require re-construction almost from the commencement.

It seems to me that to provide for such a contingency, improbable it is to be hoped, but by no means impossible, the system of tanks distributed among the barracks for catching and storing the rain water from the roofs should be carried out, and which would render the barracks independent for drinking water of supply from the water works should any serious disaster happen to them.

The cisterns were constructed without the cross walls and archways to induce a free circulation of water. This is to be regretted, as the construction of these cross walls would have added very little to the cost of the cisterns, and had they existed, it would have been possible by their means as intermediate supports to roof the cisterns at a comparatively moderate cost. The corrugated iron roofs now put up over the pure water basin and cistern in the Bakery square are supported on wrought-iron trusses carried on heavy cast-iron shoes which have to be bolted into the walls, and are very costly.

The failure of the filter and cisterns point I think to the advisability of using a flooring other than stone flags on concrete over a basement filled in with made earth. The floor of a cistern is always its weak point. When constructed of flags, unless the stones are very carefully and truly dressed, there is always a difficulty in cementing them up properly at the joints, and the space X may be left clear inducing leakage, which



once commencing may lead to grave results. Where the earth beneath the flooring is made earth, unless it is well puddled and plenty of time is given to it to set, shrinkage must ensue more or less, which by reason of the super imposed weight of water is sure to be followed by subsidence and cracking of the floor. This appears to have been the cause of failure in the cisterns. A stronger and more reliable flooring would result by constructing it of arches turned on cross walls in the basement, and brought to a level by concrete and asphalte or cement. Constructed in this way, the flooring would not be affected by any subsidence of the earth beneath, and if a water-tight floor is obtained thus, the additional cost would fall far short of the amount required to repair the filter, supposing the floor to have been constructed of flags on concrete and found to leak. The only instances where the cisterns in connection with the Ulsoor water works did not leak, are the pure water basin, the cistern at the Commissariat square, and the upper filter at the rock. In each of these cases the floor rested on firm soil or rock and not on made earth.

From the returns of the consumption of water by the troops during the last official year, it will be seen that the average daily consumption of the troops when the garrison was reduced by the absence of one Regiment of Infantry on service has been very nearly equal to the estimated demand for the garrison when at its full strength. Judging by the consumption of the past year, with the full compliment of troops in Bangalore, the amount of water used would be not far short of 50,000 gallons daily, or 16·38 gallons per head per European.

This is in excess of the estimated demand of 14 gallons per head, which, to judge by the provision made in water supply systems elsewhere, is ample, and much in excess of what was assumed as the proper demand in the project first submitted in 1862. It also exceeds what was found to be sufficient in 1871, as noted in page 21. This point deserves attention; greater economy in the consumption of the water would lead to economy in fuel and pumping.

No opportunity has yet occurred for testing the arrangements for drawing water from the filter and pure water basin at the Dhobies' wells. Water has stood high in the wells all this year, and until it falls the connections for pumping from the pure water well direct cannot be made, as the pipes where the joints have to be made are 6 feet under water. As soon as possible the connection will be made, and the working of the plan reported on.

F. J. R.

Number of wells 16, each 10 feet in diameter, together with one pump well (connected with the foregoing) of 6 feet in diameter. One foot of water in the wells is equivalent to 8,030 gallons. Storage capacity of all the wells is equivalent to 144,550 gallons. One revolution of pump shaft is equivalent to 1·79 gallons. Zero on gauge being sill of Ulsoor waste weir.

Month and date	Number of hours engine at work	Number of revolutions per minute	Total number of revolutions per day	Reading of gauge in wells morning — Below sill of waste weir Ulsoor tank: Feet	Reading of gauge in wells morning: Inches	Reading of gauge in wells evening: Feet	Reading of gauge in wells evening: Inches	Depth of water taken during pumping from wells: Feet	Depth of water taken during pumping from wells: Inches	Absolute loss of depth of water in 24 hours: Feet	Absolute loss of depth of water in 24 hours: Inches	Total number of gallons of water pumped	Depth of water re-gained by filtration into the wells — During pumping by day: Feet	During pumping by day: Inches	Engine at rest by night: Feet	Engine at rest by night: Inches	Engine at rest by day: Feet	Engine at rest by day: Inches	No. of gallons required by filtration into the wells — During pumping by day	Engine at rest by night	Engine at rest by day	Rainfall — In inches	Depth of water below sill of waste weir (Ulsoor tank) in feet	Remarks
1	2	3	4	5		6		7		8		9	10		11		12		13	14	15	16	17	18
1871.																								
20th May,	10	40·63	24,561	18	6½	17	8	8	8½	..	..	47,181	2	1½	1	1	..	..	16,989	8,700	..	..	..	The engine used was the old one since removed.
21st ,,	7½	61·5	27,700	16	2	19	10	8	8	2	7½	49,473	2	5	2	..	..	..	19,361	16,060	..	..	..	
22nd ,,	7	65 95	27,700	17	10	20	11	8	5	1	8	49,473	2	11	2	..	..	..	23,376	16,060	..	..	8·8	
23rd ,,	7	65·95	27,700	18	11	21	7	2	8	1	1	49,473	3	5	1	11	..	..	27,391	15,390	..	..	..	
24th ,,	7½	65·95	28,550	19	8	22	0	2	4	..	9	50,209	3	11	1	7	..	..	31,500	12,715	..	0·390	..	
25th ,,	7½	65·95	28,550	20	5	22	7	2	2	..	9	50,209	4	1	1	7	..	..	32,809	12,715	..	0·425	..	
26th ,,	5½	56·6	11,870	21	0	22	8	1	8	..	7	38,473	2	5	1	10½	..	..	19,421	16,779	..	0·115	..	Part of a day's work.
27th ,,	..	..	..	20	9½	20	0	..	..	..	..	..	..	..	..	8	..	9½	..	5,350	6,357	0·150	..	
28th ,,	..	..	..	19	4	19	0	..	..	..	..	..	..	..	..	7½	..	4	..	5,020	2,677	..	..	
29th ,,	..	..	..	18	4½	17	10¾	..	..	..	..	..	..	..	..	5¾	..	5¾	..	3,850	3,850	0·005	..	
30th ,,	..	..	..	17	5	16	10½	..	..	..	..	..	..	..	..	..	..	7½	..	..	5,020	0·160	4·0	

BANGALORE: 16th June, 1871. (Signed) H. W. WOOD, CAPTAIN, R.E., *Exec. Engineer, Bangalore.*

(True Copy)

BANGALORE: 30th September, 1879. (Signed) F. J. ROMILLY, LIEUT., R.E., *Exec. Engineer.*

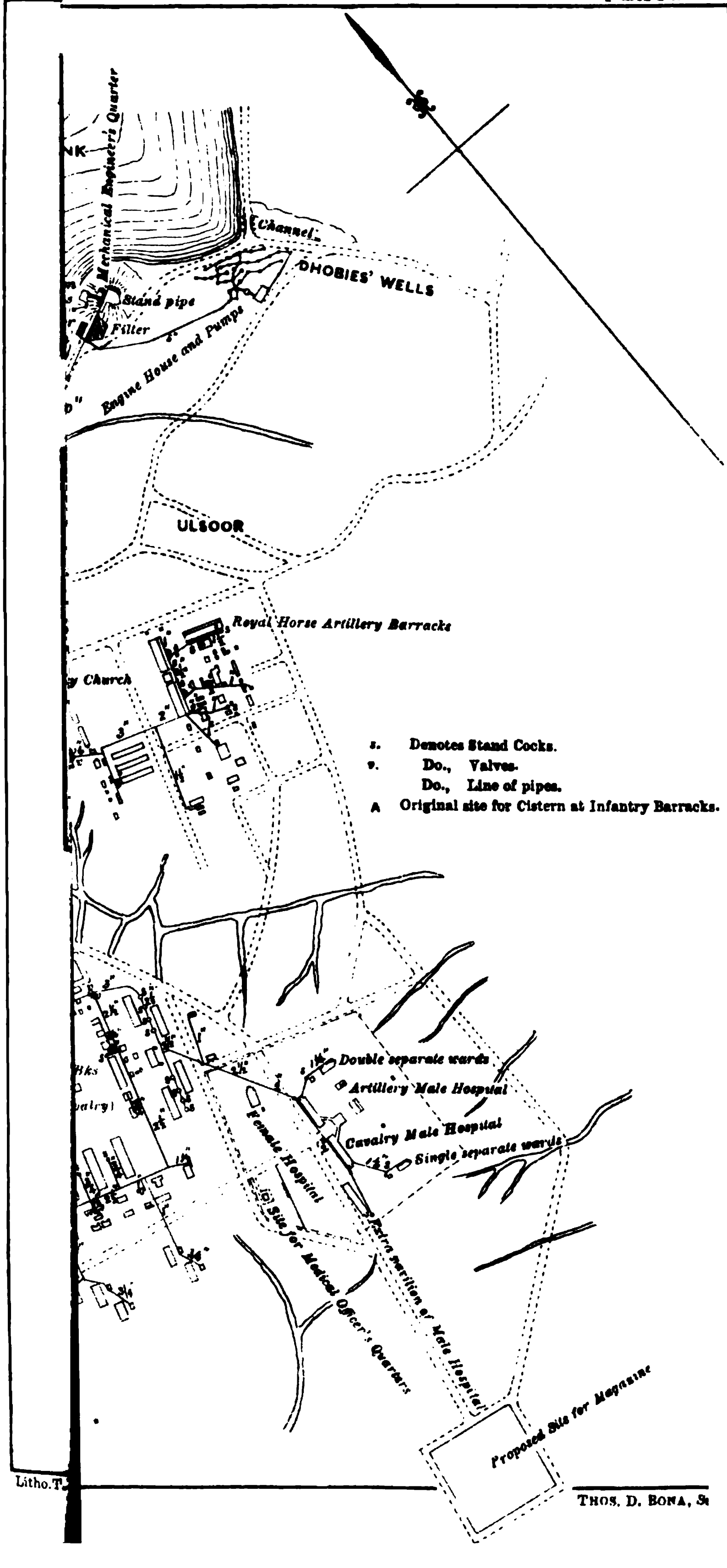


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PLATE II.

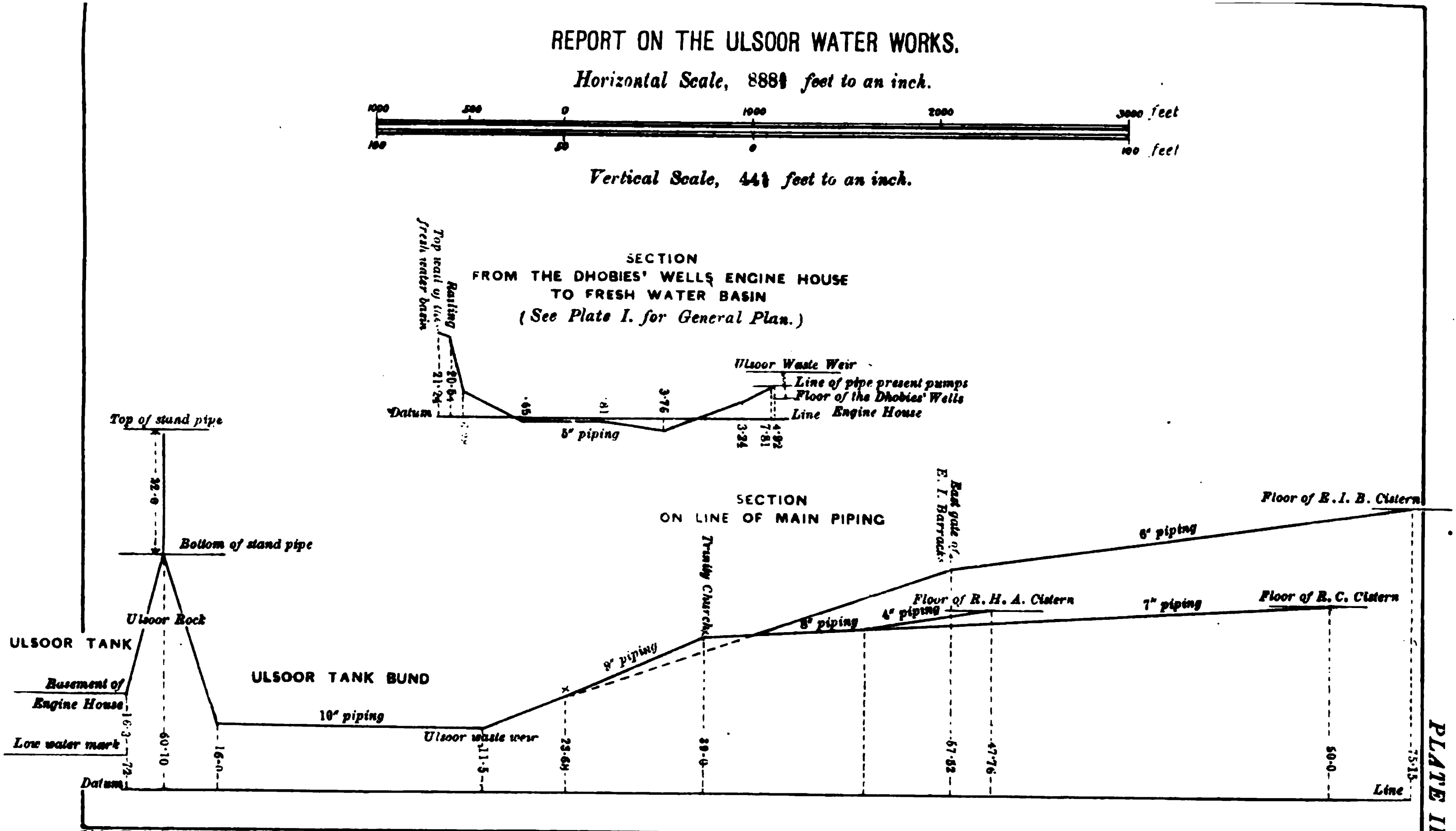

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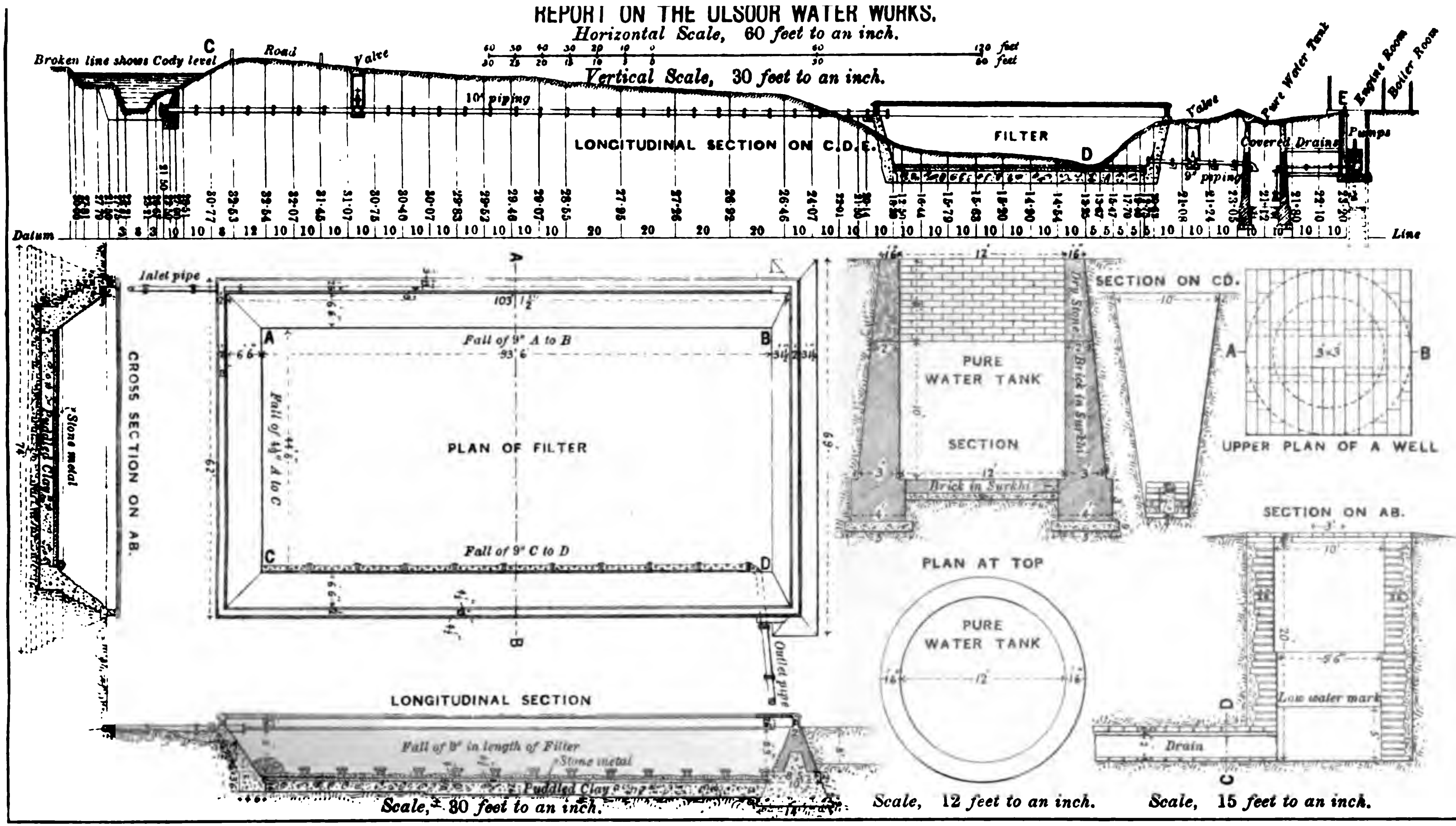
PLATE III.



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REPORT ON THE ULSOOR WATER WORKS.

PLAN OF FILTER ON THE ULSOOR ROCK.

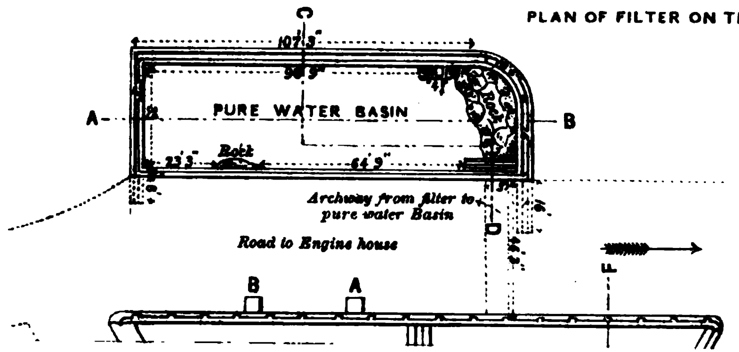
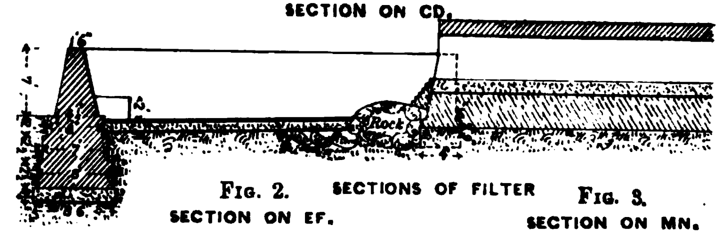


Fig. 1.

SECTION OF PURE WATER BASIN

SECTION ON CD.



SECTIONS OF FILTER

Fig. 2.

SECTION ON EF.

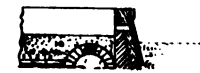


Fig. 3.

SECTION ON MN.

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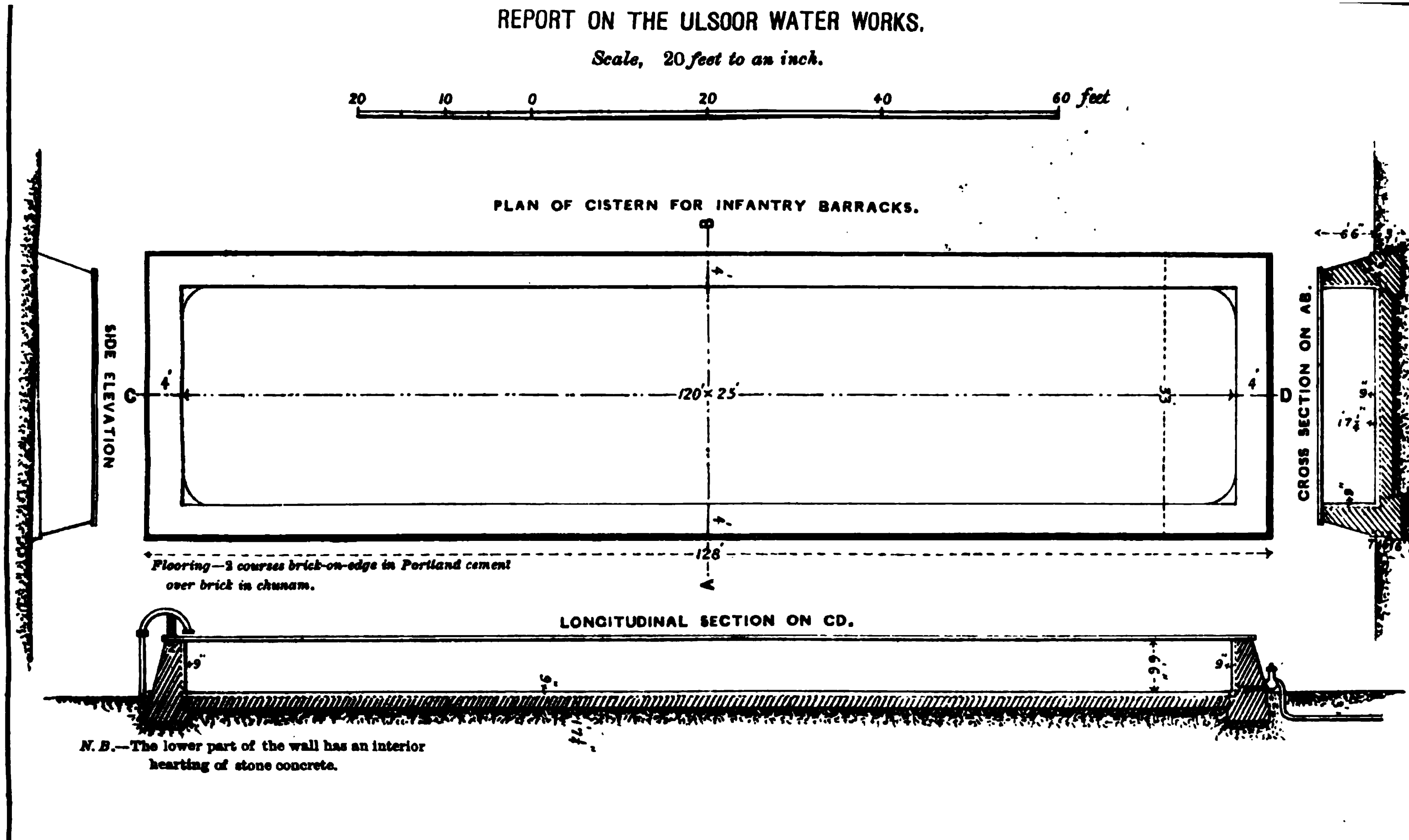
PLATE VI.



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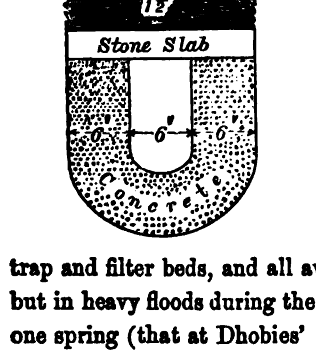
No. CCCXXXIV.

ALMORA WATER SUPPLY,

By T. W. Ashhurst, Esq., *Exec. Engineer, Kumaon Division.*

The water is collected from springs and ravines by a lateral open channel (which can be closed at will) generally cut in rock and lined with concrete. This channel is placed at about 2 feet below ground surface, and is covered tightly with stone slabs, over which there is filled about $1\frac{1}{2}$ feet of earth. It is a continuous channel constructed throughout of concrete (see sketch), and is large enough to contain double the minimum supply. The concrete is composed of 7 parts quartzite, broken to 1 inch cubes, to 2 parts sharp river sand and 1 part lime, plastered over with a plaster composed of 1 Portland cement to 8 lime and 4 sand.



During the dry weather this channel is kept free from silt and debris by silt trap and filter beds, and all available water is turned in from all springs, but in heavy floods during the rains, when the springs flow copiously, only one spring (that at Dhobies' ghat) is required for the town supply, and all others are shut off. The most distant stream is about $3\frac{1}{4}$ miles from the town.

The minimum supply in the dry season was taken at 2 cubic feet per minute, which was well under the minimum measurements taken over several years.

The population of Almora is about 8,000, so that a supply of 2 gallons per day for each person was given.

The average velocity of flow is 3 feet per second.

The filter beds have an area of 40′ × 10′, and are capable of filtering 31,150 gallons in 24 hours. The filtering medium consists of 2½ feet fine sand, 6 inches coarse sand, 6 inches fine gravel, and 2½ feet gravel, ¼-inch to ¾-inch diameter.

The storage reservoir is 100′ × 10′ × 10′, containing sufficient water for seven days' supply.

There is an ornamental fountain in front of the School house, supplied by a 3-inch cast-iron pipe, the overflow from which is collected in a waste tank at a lower level, and the distribution is made by water posts at convenient intervals and flow nozzles at the extremity in the centre of the town.

The total cost was about Rs. 21,000.

ALMORA,
13*th February*, 1880.

T. W. A.

No. CCCXXXV.

WATER SUPPLY, AHMEDABAD.

[*Vide* Plates I. and II.]

By Lieut. J. Neville, R.E., *Exec. Engineer.*

It appears that in 1849 the existing building at the head works was built by Lieutenant Dickinson, R.E., the then Executive Engineer. Water was at that time raised by means of four Persian wheels. The total cost of the building with wheels, filtering beds, air shafts, &c., was Rs. 1,09,583, obtained from Municipal Funds. In about 1865 the Persian wheels being found inadequate, pumping engines were obtained from Messrs. Nicol and Co., Bombay. Fresh distribution pipes were laid; the funds being always supplied by the Municipality.

Up to this time the execution and maintenance of works had been in the hands of the Executive Engineer; but about 1878, after some correspondence, the works were transferred to the Municipality, and looked after by the Municipal Secretary. Schemes of improvements were, however, referred in some cases to the Executive Engineer.

Population and Distribution.—An idea of the present arrangements for distribution will be obtained from the small city plan (*vide Plate* I.) which accompanies this report. Water is only distributed over about one-third of the city, and in those quarters, owing to caste, only one-half of the population avail themselves of it. Taking everything into consideration, 25,000 people, out of a total of 111,680 within the city walls, may be said to benefit by the works. As the daily supply is 133,000 gallons, consumption may be said to be 5 gallons per head per diem.

Site.—The head works are situated to the south-west of the city at the edge of the river Sábarmati, which at this point flows under the walls. The site has been strongly objected to by the Sanitary Commissioner, on the ground that this being the down-stream end of the river, all sewage and impurities discharged higher up are carried past the pumping station, thus polluting the supply at its source. In consequence of this opinion, a proposed extension of the works was abandoned. Alternative schemes of a point of supply higher up the river, and of water supply from the Khári river, have been suggested.

Pumping Engines.—The pumping station is a large two-storied building, the pumping engines (horizontal) of 5 horse-power and 6 horse-power respectively, being situated on the ground floor. The water is raised to a height of about 52 feet by iron pipes, at the lower extremities of which are flexible tubes terminated by perforated copper caps. The two engines lift together 133,000 gallons in 10 hours, *viz.*, from 6 P.M. to 4 A.M., less impurity being likely to be in the river in these hours.

Filtering Arrangements.—The filtering arrangements in the upper story will be understood from *Fig.* 1, *Plate* II.

The water is first admitted into the settling tank, which is about 755 square feet area, and 5,574 cubic feet capacity, above lowest pipe of communication with filters A and B. As, however, 133,000 gallons, or 21,280 cubic feet are pumped up in 10 hours nearly, all this must pass through settling tank to filter, and thence to storage tank and main pipe; during the working of the pumps, the value of this settling tank is doubtful. The two filtering tanks A and B have a total area of about 352 square feet. The filtering material consists of 1 foot charcoal, 2¾ feet coarse kunkur, and 6 inches finer kunkur. The process of filtration is still more rapid than that of settling, and can hardly be considered adequate.

Supply Arrangements.—The main from the pumping station consists of two earthenware pipes 8 inches in diameter. The cast-iron pipes used are of 2, 3 and 4 inches diameter. Air shafts, varying with the pressure from 30 feet in height, are constructed of brick and lime masonry, at intervals of 800 feet to 1,000 feet. Syphons called "Madians" of brick and lime used to be exclusively employed at points of junction of branch pipes as shown in *Fig.* 2, *Plate* II.

To stop a branch supply with the above arrangement, a man has to climb up and put a wooden plug in the hole A communicating with the branch pipe. This antiquated system is necessitated by the use of earthenware mains which cannot stand high pressure. With the cast-iron piping cast-iron junction pipes are used.

Water is drawn either from iron stand pipes or from covered tanks. The latter are something of the cross section shown in *Fig.* 3, *Plate* II.; and 26 hib-cocks are attached to the outer face, so that several can draw water at the same time. A man is kept in charge of each of these tanks, but it is difficult to make the people turn off the cocks after filling their vessels, and the waste is considerable. To some of these reservoirs open troughs for cattle are attached.

Water Rates.—Service pipes are laid for private supply, and the consumption is regulated by meters; the rate being 8 annas per 1,000 gallons. There are only 13 service pipes however, and the annual receipt is Rs. 225, which is credited to the general fund. There is no water rate other than that of the service pipes.

Cost of Maintenance.—The daily cost may be taken as follows:—

	Rs.	A.
Fuel (babul wood) 53 maunds, ...	13	0
Establishment, ...	9	8
Contingencies, ...	2	8
Total Rs.,	25	0

In 1878-79 the total cost of maintenance was Rs. 10,184, which gives a higher daily average than this, *viz.*, Rs. 28.

J. N.

PLAN

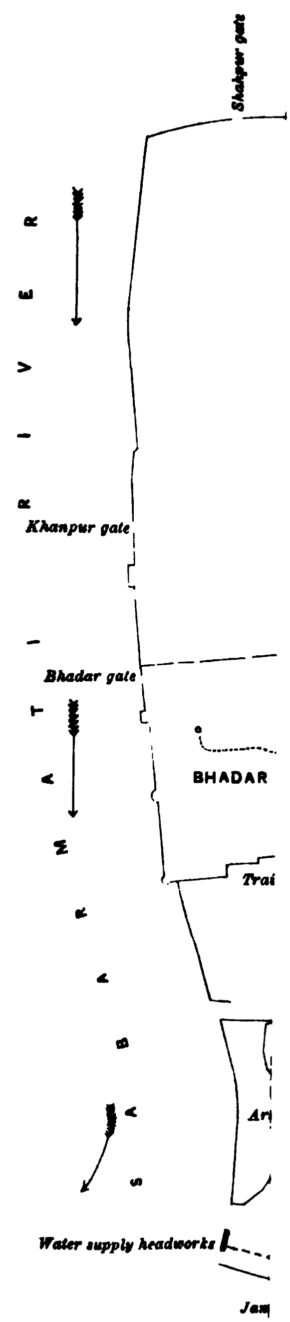


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PLATE II.

WATER SUPPLY, AHMEDABAD.

Approximate Scale, 20 feet to an inch.

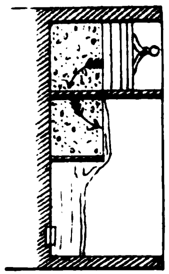


FIG. 1.

ROUCH PLAN

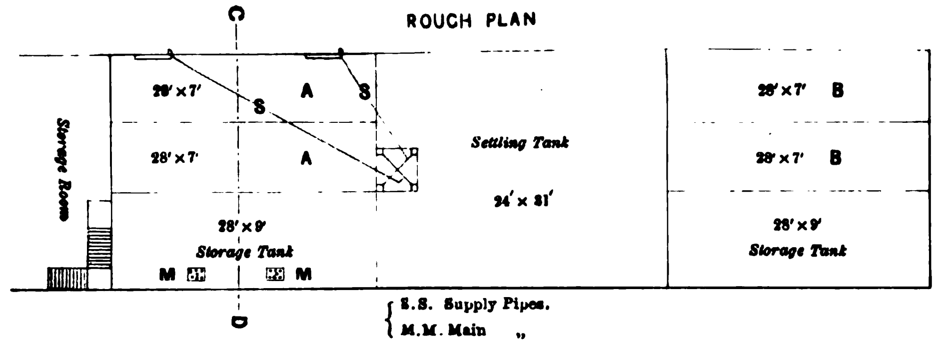


FIG. 2.

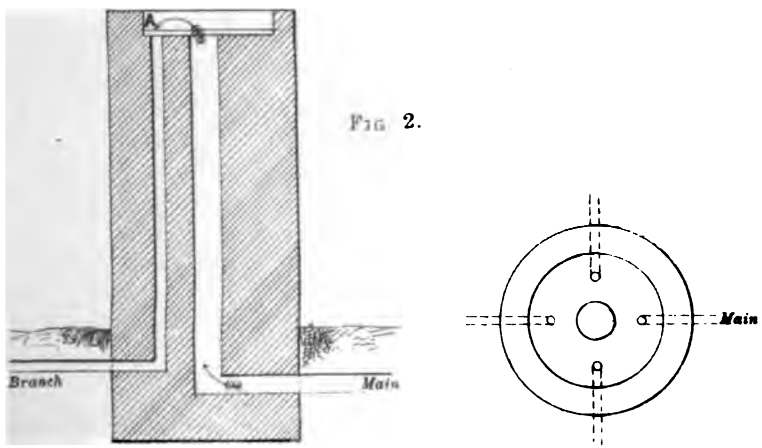
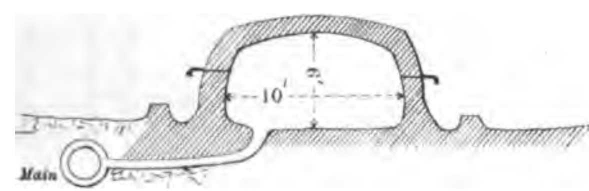


FIG. 3.



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THOS. D. BONA, Supdt.

No. CCCXXXVI.

KARANDWAD WATER WORKS.

Cost, Rs. 23,807.

Karandwad is a town of 8,000 inhabitants at the junction of the Punchganga with the Krishna River, and is the capital of one of the Southern Marátha Country States of the same name.

It draws its water supply from the Krishna, 1 mile away on one side, and from the Punchganga at about the same distance on the other.

In 1866 the Chiefs of Karandwad offered the Political Agent, Southern Marátha Country, to spend a sum not exceeding Rs. 25,000 on works for the water supply of their town. Works were accordingly designed to fall within this limit, and to supply 5 gallons per head per day, a small wind engine of 3 horse-power, under an assumed wind pressure of 2 lbs. per square foot, available on an average for 7 out of the 24 hours throughout the year, was procured from England. With this it was calculated to raise 6,000 gallons per hour to a height of 50 feet. This was erected over a well sunk in the bank of the Punchganga at 385 feet from the low water channel. It has 8 sails, each of 35 square feet area, consisting of canvas stretched over a rectangular wooden frame, with a counter-weighted feathering arrangement, adjusted so as to feather the sails if the wind pressure exceeds what is considered safe.

The well is of 10 feet diameter and 35 feet deep, and in it the pump (double barrelled 7-inch cylinders) is posted somewhat above low water level of the river. The water is admitted to the well by a masonry culvert (2′ × 5′ in section), with plug or scraper with chains attached for drawing it back and forwards and so clearing out the silt.

The water is pumped into a stand pipe consisting of a masonry tower 20 feet high, built on the bank near the well, and thence it flows by gravitation through a 6-inch pipe to the storage tank situated in the highest part of the town, a distance of ¾ mile.

Storage Tank.—The storage tank is an old one, forming part of the ditch of the old fort, to which nothing has been done. It has a capacity of 2,400,000 gallons, or about two months' supply. There is no system of distribution, the water being drawn direct from this tank.

The works were completed in 1869, but cannot be said to have proved a success. Owing to want of sufficient wind at other times, the wind engine only works regularly during the monsoon, and then, when the floods are high, it has to be stopped, as the structure is partially submerged by water, and 1½ mile from shore.

It is constantly being stopped for repairs, about which there is great delay, partly on account of there being no skilled labour easily available.

The channel connecting the well with the river gets silted up and cannot be cleared until the river has somewhat subsided.

The storage tank leaks so that water cannot be accumulated in it.

During some months of the cold weather the engine works for an hour or two a day, and the inhabitants, living near the tank, draw their supply from a small masonry *houd* built in the bottom of the old tank, and into which the pipe discharges.

No. CCCXXXVII.

WATER SUPPLY, ADEN.

[*Vide* Plate].

By Lieut. H. Clarke, R.E., *Exec. Engineer.*

The water-supply of Aden has always been a matter of considerable difficulty owing to the scarceness of rainfall, *vide* the annexed extract from the register of rainfall at the Civil Hospital, Aden :—

Year.	1872-73.		1873-74.		1874-75.		1875-76.		1876-77.		1877-78.		1878-79		1879-80.		Mean Average per mensem
Month.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	
April, ..	1	9	..	..	..	..	..	..	..	..	..	12	..	5	..	..	·16
May, ..	..	20	..	10	..	..	..	2	..	..	..	..	..	..	..	..	·04
June, ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·00
July, ..	..	41	..	2	..	..	..	..	..	..	..	..	..	..	..	3	·06
August, ..	..	98	..	27	1	58	..	..	..	14	..	..	..	22	..	15	·42
September, ..	..	21	1	28	..	..	..	..	..	64	2	73	..	..	..	46	·41
October, ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·00
November, ..	..	..	..	12	..	6	..	22	..	..	..	..	..	..	..	..	·06
December, ..	..	42	..	11	..	..	..	18	..	..	1	92	..	18	..	..	·40
January, ..	..	85	..	45	..	..	1	49	..	..	1	28	..	..	..	..	·58
February, ..	..	..	..	..	..	42	..	17	..	81	..	41	..	..	..	..	·26
March, ..	4	53	..	..	..	..	1	65	..	78	..	..	..	6	..	..	1·01
Total, ..	8	69	2	35	2	05	3	73	2	37	6	46	..	51	..	..	..

From the above it will be seen that rainfall may be expected generally in either March or September if at all. This register of course is no criterion of the actual rainfall on the hills, but will give an idea of the relative dryness of the years. It is, moreover, useless to take any water-supply projects which have been formed for Aden, to serve as guides in any respect with regard to India, because—

(1). The exceedingly scanty supply from rain, the whole annual fall here would in most places in India be frequently exceeded in a few hours.

(2). The fact that all the projects have been designed with a first view to the supply of Government employés without any reference to outsiders. They are of course admitted to the benefit of any surplus, should there be any—a rare occurrence. In describing the supply, each source has been treated separately under a single head, and as far as possible, independent of any others. The relative order is as follows:—

1. Condensed Water-supply.
2. Wells.
3. Shaik Othman Duct.
4. Tawella Tanks Supply.
5. Kussoff Valley Scheme.

Condensed Water-Supply.

In 1867 Government became at last convinced of the absolute necessity of providing a plentiful and unfailing supply of *good* water for drinking purposes; and condensers were ordered out from England.

In 1869 one was erected at the Isthmus, and afterwards one at Seerah Island; an old river flat, the *Hydrabad*, was also converted into a floating condenser and stationed at Steamer Point. The above are the property of Government; but there are beside these other condensers, the property of private individuals and firms, which supply water to the public and the shipping (with the exception of the P. and O. Company's condenser, which supplies only its own Company's ships and employés).

The need of these may be imagined from the fact that in former days the ships requiring water here have been some times compelled to pay as much as Rs. 8 per 100 gallons for brackish water brought in skins from Shaik Othman on camels.

Seerah Condenser.—This condenser house is built on the west end of the island, and is invisible from the sea-side. It was built in year 1871 at a cost of Rs. 12,900, exclusive of boilers and condensers. It holds two boilers and three Normandy's condensers, and the water was at first supplied from pipes laid in the sea. In the year 1874 an intake tank was excavated in the rock to prevent the pipes being choked with silt. It was 20 feet in diameter and 10 feet deep, and cost Rs. 900. In 1876-77 this tank was enlarged to three times its original size, to give a constant supply of water—whether the tide was in or out, and cost Rs. 3,025. An additional boiler-house was built, and an old boiler used in Abyssinia was fixed and connected with the condenser at a cost of Rs. 1,820.

The water was formerly taken from the condenser in carts or by donkeys, &c. But in 1876-77 a cast-iron tank 40′ × 40′ × 8′, holding 80,000 gallons of water in four compartments each 20 feet side, was erected in the vicinity of the European barracks. This holds a fortnight or three weeks' supply of drinking water for the troops. It is supported on masonry pillars, and roofed over with corrugated iron. Four-inch socket pipes are also laid to convey the water from the condenser to this tank—a distance of 3,200 feet. Sufficient head is given by pumping the water at the condenser to a height of 40 feet above the sea level into a cubic tank (iron) of 4 feet side, whence it gravitates to the condenser.

The cost of this work was Rs. 16,820.

These socket pipes had been lying at Aden since the expedition to Abyssinia, and had suffered greatly from exposure to the climate of Aden, which is peculiarly destructive to ironwork. They were, in fact, nearly, if not quite, worn out before being laid down, and have given constant trouble owing to leakage, both from the joints and through small holes in the pipes. New 4-inch flanged pipes are now being substituted for them at a cost of Rs. 5,000.

The evaporation from the iron tank must be very considerable. In testing the tank on one occasion with salt water before handing it over to the Commissariat Department, a fall of half an inch occurred in 24 hours, which could only be due to this cause.

Isthmus Condenser.—There are two condenser houses, each containing one boiler and condenser; they were built in 1857 and 1869 at a cost of Rs. 22,400. The water supply for condensing is obtained from a large tank (250′ × 30′ × 7′) excavated near the condenser at a cost of Rs. 2,000. This tank is situated almost half a mile from the sea, but the salt water percolates everywhere in the Isthmus, and is found at all depths, as will be seen hereafter, *vide* Wells. Two tanks built in four compartments each were erected in 1858 at a cost of Rs. 60,000, and are known as Nos. 1 and 2 Reserve.

Tanks.—No. 1 is not altogether devoted to condensed water, part of its compartment being occupied by Shaik Othman water. For particulars about size, &c., see table of Isthmus tanks on page 9. In 1876-77 pipes were laid from the pier of obstruction to the condenser tanks; these pipes are of the same class as those laid from the Seerah condenser to the large iron tank in the Crater position, and have given like them a good deal of trouble. They also are being re-placed by new 4-inch flanged pipes at a cost of Rs. 5,400. They lead from a tower 20 feet high with a masonry tank of 2 feet side at the top, into which the water pumped through a 2-inch up pipe from the floating condenser, which is thus enabled to perform double duty.

Floating Condenser.—The old river flat *Hydrabad* was converted into a condenser and moored off the Post Office pier, Steamer Point. Opposite the end of this pier, tanks of stone and mud, cement plastered inside, are built to hold 45,700 gallons, at a cost of Rs. 4,500, and pipes laid to them from the head of the pier. Formerly an iron tank of four sides used to stand at the end of the pier, supported on cast-iron pipes, and the water used to be pumped from the *Hydrabad* into this tank, and thence flowed by gravitation to the tanks. In 1875-76 an addition was made to the length of the pier by a pier-head supported on iron screw piles, and the unsightly tank removed. The water is now raised to the head required on board the *Hydrabad*, and then flows through a vulcanized flexible tube into the pipes laid along the length of the pier.

The sizes of tanks are as under—

No of Tank.	Capacity. Gallons.
1, ...	17,400
2, ...	11,300
3, ...	17,000
Total, ...	45,700

In 1876-77 the old Municipal tanks under the Assistant Resident's house were repaired and roofed over. They are of stone and mud masonry, cement plastered inside, and have five compartments capable of holding in the aggregate gallons 103,832, *viz.*:—

	Gallons.
No. 1, ...	20,964
No. 2, ...	22,219
No. 3, ...	20,531
No. 4, ...	21,293
No. 5, ...	18,825
Total, ...	103,832

These tanks are connected with the other reservoirs at the Post Office pier by means of piping. These Municipal tanks, as might have been expected from their construction, have given frequent trouble by their leaking, and some have been strengthened by masonry counterparts. It would probably be found cheaper in the end to have built new stone and lime tanks than to have expended any money on these kucha arrangements.

The *Hydrabad* is now enabled to work both at the pier of obstruction and the Post Office pier. As soon as the tanks are full at one place she proceeds to the other. The above condensers are all Government property, and supply Government employés only; they are in charge of the Commissariat Department. The amount of water which could be produced at a *stress* is as follows :—

Per diem.		Gallons.
Seerah Condenser, ...	Government Property.	9,000
Isthmus „		5,600
Hydrabad „		7,000
	Total ...	21,600
P. and O. Company's Condenser, ...	Private Property.	9,000
Luke Thomas & Co.'s „ ...		12,000
Eduljee Maneckjee's „ ...		4,000
Aden Coal Company's „ ...		6,500
	Total, ...	31,500
	Total gallons, ...	53,100

Or a supply for 10,620 European troops at 5 gallons each per diem.

The cost of condensed water to the general public is about Rs. 3-8-0 per 100 gallons, exclusive of cost of carriage. The actual cost of production to Government is about Re. 1-12-0 per 100 gallons. It may be as well to add here a table of the allowance of water provided for its employés by the Government. Officers have to pay the carriage of their water, and also the cost of any extra water drawn by them.

		Per diem. Gallons.
Officer	each, ...	10
„ wife	„	10
„ horse	„	10
„ child	„	5
„ servant	„	3

		Per diem. Gallons.
For Mess (additional) each,	... ...	5
British soldier	"	5
" wife	"	5
" child	"	5
Native soldier	"	5
" wife	"	3
" child	"	1½
Public followers	"	3
Clerks	"	5
" wives	"	3
" children	"	2½

The average rate of cost of conveyance of water in the various parts of the position is as under—

Camp, ...	7 annas	2½ pies	per 100	gallons.
Isthmus, ...	5 "	8½	"	"
Steamer Point, ...	9 "	8½	"	"

Water in addition to allowance is charged Rs. 3-8-0 per 100 gallons by Government, exclusive of carriage. Private firms can do this cheaper.

Wells.

These may be subdivided into two classes, *viz.*:—

(*a*). Those within British limits, and

(*b*). Those without British limits.

(*a*) There are about 70 wells within British limits situated chiefly in the Biggaree and Aidroos Valleys, which are in charge of the Commissariat Department, water from which is supplied to the native troops and followers, cattle, &c. With very few exceptions the water is brackish in all of these wells. They average from 120 feet to 190 feet in depth, and in the best the water stands at a depth of about 70 feet below sea level. The sweetest water comes from the Banian well, situated near the old Residency and under the Kussoff Valley, which yields a daily average of 2,500 gallons. This is private property, the temperature of the water being 102° Fahrenheit. In the opinion of Lieutenant-General Wilkins, R.E., *vide* his Report, dated 13th January, 1857, the supply of water in the wells is due to rain and dew, and the wells are not artesian as was suggested at the time. Many attempts were made to ensure a supply of good water by boring, &c., after our first occupation, but with very slight results. In the Isthmus salt water was met with at a depth of 245 feet below ground, and also in Biggaree Valley at a height of 70 feet above sea level. In this latter case the salt was probably due to saline deposits in the water-bearing stratum.

(*b*). On the northern side of the harbour there is a piece of neutral ground (nominally British territory) called the Huswah, where the bed of a mountain torrent meets the sea. Sometimes, (though very rarely) after very heavy rainfall on the neighbouring hills, this torrent empties itself into the harbour; but in general it sinks into the bed of the river several miles inland.

From wells dug in the bed of this water course, a limited supply of water can always by obtained. It is brought over to the southern side either in boats or else in skins by camels across the Isthmus.

Water of fair quality is also obtained by wells near the village of Shaik Othman, and conveyed into Aden by camels. During the hot weather the Huswah and Shaik Othman wells supply a very large portion of the water used by the civil population, as about 3,500,000 gallons of water pass the Barrier Gate in a year. The Huswah water was supplied to the troops at Steamer Point for a short time this year, but has been pronounced by the Government Analyser, together with the Shaik Othman Duct water, to be utterly unfit for potable purposes, and the supply has since ceased. It, however, constitutes the chief supply of the poorer native population at Steamer Point.

The Shaik Othman Duct.

In the year 1867, the British Government entered into an agreement with the Sultan of Lahej, by virtue of which they gained permission to construct an aqueduct from two of the best wells at Shaik Othman to the British lines—a distance of between 6 and 7 miles. The British Government were to bear the expense of construction, and half the profits, deducting the working expenses, were to be handed over to the Sultan of Lahej's Agent.

The two wells are 10 feet in diameter and 25 feet deep, and are steined with stone and lime masonry. The water is drawn from the wells by Burgess and Key's pumps, which are worked by one camel each; and is pumped directly into the duct. These pumps can each supply about 24,000 gallons per day of 24 hours, if necessary.

The duct itself is a low masonry wall on which a channel 9" × 6" is built, and covered in with slabs set in mortar. The original intention was to follow the line of the old Bir Mahait Aqueduct, and make use of it as a foundation for the aqueduct; but it was found too unsafe to be used as a foundation. The duct is carried over the creek at Khore Muxar on a stone causeway, which does the double duty of carrying the duct and providing a roadway into the interior. The sides of the causeway are pitched with dry rubble masonry. The wall or duct is covered with earth rammed to a triangular section, and at intervals of about 1,000 feet is a small cesspit or cistern to catch impurities and to prevent earth from choking up the channel.

The duct terminates at the reserve tanks in the Isthmus, and the total cost was Rs. 2,96,933.

It was originally intended to extend the work up to Dharab, 8 miles further inland; and there to tap the torrent (already mentioned under the heading wells), and take advantage of the heavy rain during May, June, July, August and September on the hills, some 20 miles further inland.

There is a stone and lime masonry tank or expense reservoir at Khore Muxar, containing two compartments each 60′ × 8′ × 2½′. Each compartment holds over 6,000 gallons, and water for the Aden troop is supplied from here. Cost Rs. 5,000.

In the Isthmus there are four tanks of various sizes. They are built of stone and lime masonry and vaulted. The arches are gabled over, and the spandrils filled in with earth to keep the whole cool.

These tanks are capable of holding an aggregate of gallons 1,359,000, and cost Rs. 95,000.

They are all connected by pipes.

An estimate has been sanctioned by Government for laying pipes to connect the Tawella tanks with those of the Isthmus, so as to ensure a reserve of rain water in addition to that obtained from the condenser. This estimate amounts to Rs. 13,500, but has been put off until funds are available.

The quality of the duct water is brackish, and it has been condemned by the Government Analyser as unfit for drinking purposes.

It is issued to the troops for ablution, &c., and a limited quantity is sold to, and drunk by, the poorer natives who get it at Re. 1 per 100 gallons. The Sultan of Lahej's half share of the profits amounts on the average from Rs. 1,000 to Rs. 1,200 per month. Until men are accustomed to drink the water, it is apt to produce bowel complaints.

An analysis of the water from the Shaik Othmam Duct and also from the Huswah is annexed; also a table of the Isthmus tanks and their capacity and present occupation.

Extract from Report of Analyst on Water.

A.—Sample of aqueduct water, 1st June 1879.
B.—Water from Huswah, 2nd June 1879.

	A.	B.
Total solids in grains per gallon, ...	368·2	471·1
Chlorine in grains per gallon, ...	100·10	175·70
Free ammonia in parts per million, ...	·01	·32
Albd. ammonia in parts per million, ...	·07	·08

Sediment—
A.—Copious vegetable *débris, Paramœcia auquellilæ.*
B.—Copious vegetable *débris, Actenophrys sol. eutomastræa auquellilæ.*

Extract from Sanitary Commissioner's letter.

2. "Of the two samples, that marked A can be used for ablution, and it might be used for cooking. Sample B can be used for ablution, but it is not recommended for cooking."

3. "Obviously neither sample is fit for drinking."

List of Tanks in Isthmus.

Locality.	Number of compartments.	Size of each Compartment. Z	B	Height to spring in of arch.	Capacity of each tank in gallons.	Remarks.
Victoria Bastion Reserve Tank,	8	100	10	8½	391,000	Shaik Othman water.
" Expense " "	6	60	8	2½	38,000	" " "
Near N. I. Lines No. 1 Reserve Tank, ...	4	44	42	8½	310,000	Part Shaik Othman, and part fresh water.
Near Condenser No. 2 Reserve Tank, ...	4	44	42	8½	310,000	Condensed water.
Little Isthmus No. 3, ...	4	44	42	8½	310,000	Shaik Othman water.
Khore Muxar, ...	2	60	8	2½	12,000	" " "

List of Tawella Tanks showing their Capacity in Gallons.

	Number of Tank.	Contents.	Remarks.
Government Tanks, ..	1	1,255,424	Coghlan Tank.
	2	64,881	
	3	21,011	
	4	160,987	
	5	185,919	
	6	70,944	
	7	396,964	
	8	4,645,273	
	9	210,000	
	10	128,786	
	11	328,501	
	1	7,418,690	
Rented to Pársis and Natives, ..	No. 1 to 8	2,835,000	Playfair Tank.
		500,000	Pársi Tank.

Tawella Tanks.

There is no certain record of the date of the construction of these tanks, which were, however, probably constructed about the date of the second Persian Invasion of Yemen, A.D. 600. In the centre of the Peninsula of Aden is a range of hills, which rises almost perpendicularly to a height of 1,760 feet, and forms the wall of the Crater of Aden. On the western side the hills are very precipitous, and the rain water descending from them is carried rapidly into the sea. On the interior or eastern side, though the hills are equally precipitous, the descent is broken by a large table-land, which occupies about one-quarter of the superficial area of Aden. This plateau is intersected by numerous ravines, which converge into one or two valleys, which thus receive the largest part of the drainage of the Peninsula. The steepness of the hills and the scantiness of the soil prevent a great amount of absorption, and thus a moderate fall of rain causes a rush of water, almost amounting to a river, before it reaches the sea.

To collect and store this water these tanks were constructed. They are very fantastic in their shapes. Some being formed of a dyke built across the gorge of a valley: in others the soil in front of a re-entering angle on the hill has been removed, and a salient angle or curve of masonry built in front of it; while every feature of the adjacent rocks has been taken advantage of, and connected by small aqueducts to ensure no water being lost. The overflow of one tank has been conducted into the succeeding one, and so a complete chain has been formed, reaching to the town. There is a tradition that about A.D. 1500, the then Governor had succeeded in reaching sweet water in wells dug by him, and in consequence allowed these tanks to go to ruin. This they would very soon do from action of *débris* washed down from the hill sides; there being no shield bunds.

The rainfall of 1859, when the tanks were in process of restoration, though the channel for about quarter mile had been cleared, brought down such a mass of *débris* as nearly to fill No. 1 tank.

Altogether there are about 50 tanks, which, if all cleared out, would hold an aggregate of about 30,000,000 gallons. Those actually in use number about 13, with a capacity of 10,753,690 gallons. The restoration of these works was commenced about 1854 by Captain Playfair, Assistant to the Political Resident, and the expenses were met by the Municipal Funds, and the money realized by the sale of water. In 1857 the charge of their restoration was handed over to the Executive Engineer, Aden.

In 1859 the Executive Engineer, Aden, (Major-General Fuller, R.E.,) found it necessary to add a shield bund above No. 1 tank, to prevent the *débris* from the valley being washed into the tank. Experience gained by a heavy fall of rain after this, induced him to raise this first shield bund to a height of 35 feet instead of 15 feet as at first, and to add a second shield bund above this (1860), and in addition at the necks of the water-courses other bunds were constructed (all with gratings at the bottom) to resist the rush of *débris* brought down from the Shum Shum Range.

These upper bunds were all placed at narrow necks, and their sites being tolerably level above the bunds, facilitated the removal of *débris* to either side,—a thing which in the lower bunds would have proved a matter of considerable difficulty, owing to the precipitous character of the valleys. All these bunds are of stone and lime masonry, with gratings in the bottom to allow water to pass when it has rained slightly, before it can be absorbed by the rocks. The tanks are all plastered excavations, varying in depth from 10 feet to 60 feet. Each tank is connected with the succeeding one by an open or covered duct, and as soon as one is full, the water is conducted to the next until the entire system is full; and when the last (Playfair tank) has received its supply, the surplus water is carried to the sea by a channel 60 feet wide, the sides of which are of dry rubble (slope 1 to 1) with a masonry coping; across it at every 30 feet masonry bunds are run below the surface to save the bed from scouring.

The plan of Playfair tank is somewhat remarkable. It is built in a series of rings or offsets, rising about 5 feet each, and the tread being 1 foot.

There are two places where these offsets have been omitted to facilitate the drawing of water. Over each a pulley can be arranged for hoisting a bucket. All the tanks are furnished with flights of small steps, constructed where convenient or necessary, and a bridge across Coghlan tank gives access from one side of the ravine to the other. Coghlan tank, the largest of the Government tanks, holds 4,645,273 gallons, and has its side cemented and floor asphalted. It is perhaps worth noting that the No. 1 shield bund built by Major-General Fuller, R.E., in 1859 re-paid its cost in the first heavy fall of rain by preventing accumulation of *débris* in No. 1 tank.

The cost of removing this after the storm of September 1859 was Rs. 4,509-6-6, and the cost of the bund then erected Rs. 2,235-0-6. Since their restoration these tanks have only three times been filled, *viz.*, in May 1864, in May 1870, and in September 1877. The heavy rainfall of 1872-73 did not entirely fill them. During such times as there may be water in the tanks the camp condenser is not worked.

The water collected is issued for the use of the troops, and is also sold at Re. 1 per 100 gallons. In September 1872 a rainfall of 2·75 inches fell in one hour, and an hour afterwards all the tanks were full, and a large quantity of water passed off into the sea.

The Playfair tank is leased by Government to some natives. It holds 2,835,000 gallons, and its owners are bound by the terms of their lease not to exceed the Government rates for the sale of water.

The total cost of the restoration of these tanks has been to Government Rs. 3,60,000.

Kussoff Valley Lakes.

Projects for the construction of reservoirs in the valleys overhanging the Banian temple have been constantly brought forward since 1845. Detailed plans and estimates were first worked out by Captain (now

Major-General) Fuller, R.E., in 1861. On his original design the work, as it now stands, has been based, though various modifications have been from time to time introduced in the several revisions of the scheme, until the one finally sanctioned in August 1873, which was prepared by Major Ducat, R.E. Major-General Fuller, R.E., proposed to build three main dams with shield bunds above them, and a tunnel in the rock through the side of the valley to act as a waste weir. He also proposed to build an expense reservoir near the old Residency, and to have pipes connected with the covered reservoirs in the Isthmus position. The subject of the thickness of the masonry in the main bund (No. 3) was discussed at some length by Government. In consideration of the frightful destruction which would ensue should this bund fail, Government decided to have the bund made 18 feet thick at the top and 42 feet at the bottom, with a mean thickness of half its height (*i.e.*, 30 feet) as against the section proposed by General Fuller, R.E., which was 12 feet top and 27 feet bottom thickness.

Captain Pym, R.E., revised the plans in accordance with orders received from Government in June 1864, and proposed doing away with the tunnel weir into the Biggaree Valley, and the extension of the piping to the Isthmus.

He considered that the tunnel weir would be so seldom if ever required that it was not worth while going to the extra expense. His revised estimate amounted to Rs. 2,14,993.

Captain Mander, R.E., in revising retained Captain Pym's sections of the dams, added by order of Government an extra dam below No. 3, to impound water for building purposes; reverted to General Fuller's waste water tunnel weir, and altered the intake head works to the supply sluice; he preserved Captain Pym's single reservoir near the Residency, and adjusted the rates, thereby making estimate amount to Rs. 2,92,723. Major Ducat's final revision amounted to Rs. 3,75,821. The general scheme submitted consisted of three large tanks and one small one on the plateau below Shum Shum. Bunds were to be built across the valley, and shield bunds across the water courses leading into the tanks, to prevent the accumulation of deposit. The small bund was intended to assist in the collection of water to help to build the other bund (No. 3). The two main tanks were to be connected by pipes, and from No. 3 the supply of the garrison was to be drawn. The total contents of the three tanks was estimated at 5,697,120 cubic feet. The works proposed consisted of the following :—

No. 1 *Shield Bund*—height 30 feet, width-top 9 feet, bottom 21 feet. Estimated cost Rs. 9,056.

No. 2 *Shield Bund*—width-7·5 feet top, 17·5 feet bottom, height 25 feet. Estimated cost Rs. 8,670.

No. 1 *Main Bund*—width-15 feet top, 35 feet bottom, height 50 feet. Estimated cost Rs. 46,922. Capacity 1,419,600 cubic feet. Cubic feet per Rupee 30.

No. 2 *Main Bund*—width-top 20·5 feet, bottom 47·5 feet, height 68 feet. Estimated cost Rs. 1,21,255. Capacity 706,320 cubic feet. Cubic feet per Rupee 6.

No. 3 *Main Bund*—width-top 18 feet, bottom 42 feet, height 60 feet. Estimated cost Rs. 1,27,628. Capacity 3,571,200 cubic feet. Cubic feet per Rupee 27.

Extra Bund—Rs. 4,596, piping Rs. 17,827; expense reservoir Rs. 4,275, tunnel Rs. 15,696.

On submission to Government, No 2 dam was rejected as not yielding results commensurate with its cost, and No. 2 shield bund was also directed to be omitted. It was proposed in the first place to carry out a portion of the work only, *viz.*, No. 3 bund to be carried to a height of 30 feet only instead of 60 feet as in the complete project. No. 1 shield bund, the extra bund, and expense reservoir and iron piping were included in this estimate, which amounted to Rs. 1,08,777. In carrying out this portion of the scheme (the only portion as yet completed) the extra bund was abandoned, as the solid rock on which it was to be founded was not met with until at a depth of 15 feet below ground, which would have brought its cost up to Rs. 12,434; it had also from the first appeared doubtful, if it would have answered its purpose, when completed; owing to the shattered nature of ground overhanging the Banian well, near which it was proposed to place it. Considerable doubt was felt as to whether the bottom of the tanks would hold water; and it was with a view to test this that No. 3 dam was only completed to a height of 30 feet in the first instance.

Both Captain Mander and Major Ducat thought it would perhaps be found necessary to plaster the bottoms of the tanks at a probable increase of expenditure of about Rs. 2,00,000 at least. In addition to this the latter expressed a doubt whether a sufficiency of rain would fall to fill the tanks and keep them filled.

Even such an exceptional fall as 7 inches, *making no deduction for absorption*, would not fill the three tanks. This was one of the reasons for the abandonment of No. 2 main bund.

As regards the construction of the bunds, the foundations were carried down to solid rock, the lower foundation being built in Portland cement, as also is the whole of the front and back of the wall (including the steps in the sides). The face stone being dove-tailed.

The hearting is built in pumice and lime mortar, without horizontal courses, the work being *vertically* bonded, so as to obviate leaks through the dam.

In the bottom of the bund is a tunnel arched over, in which the pipes are laid and covered over to prevent the scour through the sluice, when open, destroying them, while at the same time it allows of the pipes being examined at any time with perfect safety.

The inner mouth is fitted with a sluice door which converts the tunnel into a waste weir.

An isolated water tower is not provided, but instead a semi-circular well or cistern with walls 4 feet thick has been built on in front of the dam. At every 10 feet in height are bell-mouthed bent pipes fitted into the circular portion of the wall to fill the well.

The valves are cast-iron, covered with leather, which fit into the bell-mouths, and are raised by chains attached to a 6-ton crab winch which also works the sluice in the tunnel. In case of an emergency if all the valves are opened and the sluice gate also, it is calculated that the head of pressure on the dam can be reduced 10 feet in about 3 hours, which should be sufficient. The full section is completed up to a height of 30 feet, including valves, tower, &c., but as an additional precaution for the present, the centre 20 feet of the dam is raised 5 feet above the rest, the side portions being paved so as to act as weirs. The centre portion unpaved will thus prevent the overflow water falling on the pipes. When the bund is being completed the paving will be removed, and re-laid on the top of completed bund.

The expense reservoir is simply a small tank house, capable of holding about 2,000 gallons, and is above ground, so that water can be issued from outside by a stop-cock.

The portion of the project sanctioned was completed in 1875, and in September 1877 a fall of 2″·75″ filled No. 3 tank to a height of 28 feet, but it all disappeared in 36 hours' time.

No appreciable difference was noticed in the height of the water in the wells underneath at the time, but it perhaps eventually percolated into them. Under any circumstance by the stopping of this large body of water great damage to the buildings was avoided. For instance, in former years, after a heavy fall, General Fuller, R.E., reported the Executive Engineer's office full of water up window sills, *viz.*, 2 feet.

It appears on the whole unlikely that Aden will be able to dispense with any of her existing sources of water-supply.

It is true that it is said that the climate is gradually changing, but as yet we have not achieved an annual rainfall. Nor do we seem likely to get it. Without a regular and comparatively heavy rainfall there seems a probability of the Kussoff Valley lakes remaining for the greater portion of their time empty.

H. C.

Litho. T. C. Press, Roorkee.

No. CCCXXXVIII.

INCHALKARANJI WATER WORKS.

Total cost, Rs. 1,11,174.

Inchalkaranji is a town of about 8,000 inhabitants, situated about 17 miles east of Kolhápur on the north bank of the Punchganga river, and is the capital of a Jahagir of the same name feudatory to Kolhápur.

Its water supply has hitherto been from wells, and from the river about one mile from the town.

A design for supplying the town with water, at the rate of 5 gallons per head per day, pumped from the river by means of a wind engine, was made by Major Mant, R.E., and carried out by Major Ducat, R.E., with some modifications made by the Superintending Engineer, Southern Division, as to the position of the wind engine.

In the original design the wind engine was to have been erected on the bank and pumped from a well, but from experience of a similar work at Karandwad, it was decided that the pumps should work directly over the river, so a masonry tower 35 feet high was built close to the edge of the low water stream; its top, a few feet higher than the river bank, and on this the iron cross braced framework (30 feet high to axis shaft of sails) of the wind engine was erected.

The latter was calculated to give 6 horse-power with a wind pressure of 1½ lbs. on the square foot, which pressure was assumed to be available on an average 6 hours out of the 24 throughout the year. This assumption proved to be excessive, and such a pressure for such a daily duration could only be obtained during the height of the south-west monsoon. The pumps are 6-inch treble barrelled, and have to lift 80 feet, 18 feet of this by suction.

The water is pumped first to its full lift of 80 feet into a stand pipe consisting of an iron cistern or box raised on an iron cross braced tripod 50 feet high, erected on the river bank, of which two legs form respectively the up and down pipes. The water flows from the stand pipe by gravitation through a 7½-inch main, a distance of 1½ miles to the storage tank situated in the highest part of the town.

This storage tank will hold 1,200,000 gallons, one month's supply for the town, and was formed by enlarging some old quarries, lining their sides with masonry and puddling the bottom. Before entering the tank, the water passes by upward filtration through a filter bed of two compartments for alternate use. The filtering medium, 4 feet thick, being of layers of broken stone, gravel and sand.

Distribution.—The water is drawn off from the storage tank by bell-mouthed intake pipes at various levels which pass into a valve well, from which the 5-inch supply main carries it into the town, and by various branches supplies four square masonry *houds* or dipping wells 12' × 6' × 3' each of two compartments, for use by different castes, and two cattle troughs, distributed about the town. The discharge into each of these is regulated by a ball-cock.

The works were completed in 1876, but after two years' trial it was found that, except during the south-west monsoon, the wind at Inchalkaranji was totally insufficient to work the wind engine, even though after the first trial its original sail area had been considerably increased. It was determined therefore to replace the wind engine by one of Tangye's vertical boiler, 8 horse-power high pressure steam engines adapted to burn wood fuel. To place this above the level of highest flood, the masonry tower in the river was raised 12 feet, and an engine room built on top, the engine and gearing being carried across the hollow interior of the tower by three wrought-iron girders. This work is now all but complete, and the engine about to be tried. It is calculated to raise 11,000 gallons per hour, and so give a supply of 10 gallons per head per day by working eight hours per day.

No alteration has been made in the rest of the works.

		Rs.
Cost of	masonry tower in river, ...	11,916
"	wind engine and pump, ...	14,404
"	rising main 7½-inch cast-iron pipes, ...	22,358
"	replacing wind engine by steam engine,... ...	10,235
"	storage tank, ...	23,509
"	distribution by iron pipes, including valves, &c., ...	20,637
"	masonry *houds* or dipping wells and cattle troughs,	8,115
	Total, ...	1,11,174

No. CCCXXXIX.

DESCRIPTIVE ACCOUNT OF THE SYSTEM OF WATER SUPPLY BY MEANS OF STEAM PUMPING FOR THE EUROPEAN TROOPS OF THE HYDERABAD SUBSIDIARY FORCE AT SECUNDERABAD.

By Capt. H. C. Fox, R.E., *Exec. Engineer, Secunderabad Division.*

The European troops of the Hyderabad Subsidiary Force, stationed at Secunderabad, in the Deccan, consist of :—

	Men	Officers.
1 Cavalry Regiment, ...	594	30
1 Battery Horse Artillery, 2 Light Field Batteries, 1 Heavy Field Battery, ...	675	30
2 Infantry Battalions, ...	2,450	80
	3,719	140

and are located, except the Heavy Field Battery, in permanent barracks, which, within the past 25 years, have been gradually constructed on the high ground known as Trimulgherry, which lies to the north of the town of Secunderabad. The barracks are now complete except a portion of those required for the Heavy Field Battery, pending the construction of which, that battery is quartered at Secunderabad, and a few subsidiary buildings for the completed barracks. A system of water supply for these barracks, by means of steam pumping from wells into service reservoirs, whence the supply is distributed in the usual manner by piping, has recently been completed; and the following is a general description of the system and of the results of its working.

The site may be generally described as a plateau running north and south, about 4 miles long and about 1½ mile wide, the highest part being at the north, and about 1,800 feet above sea level. The plateau is a spur of the watershed ridge between the rivers Godavery and Kistna, and apparently has but little less elevation than that of the watershed ridge, although the plateau is distant about ten miles south of the actual watershed line. As might be expected under such conditions, the only way of obtaining a permanent water supply at Trimulgherry is by means of wells; and fortunately no difficulty in thus obtaining a sufficient supply for the new barracks has been met with. The geological formation of the site is the same as that found throughout the most part of the Deccan, namely, "Syenite" granite, the surface of which has undergone, and is probably still undergoing, slow decomposition under atmospheric influences, the result being that the inequalities of the rock surface have become filled with beds of "moorum," interspersed with rounded "cores" of granite which have resisted decomposition. The annual rainfall averages about 30 inches; and on most places in the Trimulgherry plateau wells sunk in the moorum have a water level of 15 feet below surface at the end of monsoon, and 35 feet at the end of the dry season, *i. e.*, in ordinary seasons.

Sources of Water supply in use by the Troops.—As the different sets of barracks were built, about four wells per regiment were sunk in the regimental lines, and the water supply from these wells, supplemented in exceptionally dry seasons by water carried from more distant sources, was, it is believed, always found sufficient for all regimental purposes. With a view, however, to ensure a regular and pure supply of water for purposes of drinking, cooking, and washing, in connection with the troops, a system of water supply by steam pumping from two specially constructed wells was undertaken about ten years ago, and was completed last year. The number of persons supplied is shown above, and at 16 gallons per man and 80 per officer, this gives a total quantity of water—70,704 gallons—supplied daily. The supply has been found to be ample though not excessive. The adequacy of supply from the two new wells was tested by prolonged trials, in one well lasting 343 days, water being pumped from the wells and passed through meters. The supply was found to be sufficient, and the purity of the water very satisfactory. The old wells are now used for filling plunge baths, watering horses, and providing water for tatties and gardens, and for flushing drains, &c. The system was constructed in two sections; the first or south water supply being commenced in May 1867 and taken into use in May 1874, while the second or north water supply was, except the construction of the well, taken in hand in 1878 and completed in 1880. The two systems will be described separately.

South Water supply.—The south water supply well with its main service reservoirs, and distributing system gives water supply to one of the Infantry Regiments and to the double-storied hospital, which is used by both Infantry Regiments. The well is cylindrical, 30 feet in diameter, and 55 feet deep below surface of site, and is steined with granite, built without mortar where springs occur. Above ground the well is provided with a parapet and a domed roof of zinc on iron frame-work. Water is pumped from the well by machinery, to be described hereafter, to two service reservoirs at different levels, whence the supply flows by gravitation to the taps, whence it is drawn for use. The high level reservoir supplies the hospital and the officers' quarters, while the low level reservoir supplies the men's barracks and the family quarters. The necessity for thus dividing the supply arises from the levels of the ground. The upper storey of the hospital is at too high a level to be supplied by gravitation, but receives its supply from a small reservoir in the lower storey, whence water is pumped by hand to cisterns in the upper storey.

Pumping machinery—Tangye and Holman's Special Pumps.—The pumping machinery originally fitted in this well consisted of a pair of Tangye and Holman's special direct acting steam pumps with vertical cross tube boilers, the pump and the boiler being fixed on the same bed plate in each set (for full description and drawing of this arrangement see Section E., page 29 of Messrs. Tangye and Holman's catalogue of 1867), the diameter of the steam cylinders being 7 inches, that of the water cylinders 5 inches, and the length of stroke 12 inches. The boilers were fed by miniature special pumps fixed to the bed plates, and each set of this machinery should have been capable of pumping 5,000 gallons of water per hour. The machinery was placed in a masonry shaft close to the well, the pumps being about 30 feet above the bottom of the well, and 25 feet below the surface of the ground. A U-shaped stand pipe, the summit of which was a little above the level of delivery pipe at high level reservoir, was fixed on the delivery main, and provided with a cross pipe and valve at the level of the low level reservoir delivery, so that it could be used with the latter.

The whole of this machinery proved unsuccessful in use, and was removed after about a year's trial. The machinery was supplied before the railway was opened to Secunderabad, and its failure was, no doubt, partly due to there then being no fitters and engineers locally procurable and having knowledge of the structure and management of pumps of the above description. Moreover, the boilers being placed in a pit 25 feet deep, and only about 16 feet wide, the heat in the pit was very great; and it was found that the engine driver and firemen could not attend properly to their work when the boilers were under steam. The pumps worked fairly well, except that the reversing tappet valves (*see* page E-32 of Tangye and Holman's catalogue) were very apt to stick and stop the pumps; but the small feed pumps, owing to the extreme smallness of their working parts, could not be kept in working order, and there was consequently always danger of low water in the boilers. The latter defect was remedied by attaching injectors to the boilers, but nevertheless, as, on the whole, the machinery was evidently unsuited for its purpose, it was eventually decided to remove the machinery altogether. One defect in the pumps was the loud banging noise they made at every stroke, which caused great annoyance to the officers whose quarters are near the well.

Ransome and Rapier's pumps.—The pumping machinery now consists of a pair of Ransome and Rapier's double-acting lift and force pumps. Each of these is driven by rods and gearing worked by a small engine and vertical boiler placed on the surface level close to the well (for a drawing and description of this arrangement see in *Spon's* Engineering catalogue, page 79). The size of the pumps is—diameter 6″ × stroke 12″, that of the steam cylinder, diameter 8″ × stroke 10″. The boilers are placed in a fairly spacious engine house; and the pumps are in shafts 25 feet above the bottom of the well. This machinery has worked well since 1875. The amount of water which can be delivered per hour depends much on the depth of the water in the well, and on the quality of the fuel supplied by the Commissariat Department; but, speaking generally, it may be said that one pump can fill the two service reservoirs with 72,000 gallons, or three days' supply in about fifteen hours, or, say, two days' pumping. This gives an average delivery of 5,000 gallons per hour for one pump. One pump only is worked at a time, the other being kept as a reserve in case of a break-down, or when repairs are necessary. The supply is delivered into the service reservoirs by a 4-inch main to the high level, and a 5-inch main to the low level.

The high level main is always kept open, and is provided with a short open vent at its summit, so that it acts as a stand pipe. The old stand pipe has been taken down.

Reservoirs.—The reservoirs are rectangular masonry chambers half sunken in the ground, and flat roofed with massive granite slabs. Each reservoir has two compartments, so that the supply may be kept up should the reservoirs require repair or cleaning. The masonry of the reservoirs is of granite in lime mortar, plastered inside with Portland cement. The sides are protected with earthen banks, and the roofs are made water-tight with plaster. These reservoirs serve their purpose very well.

Distributing Mains and Piping.—The contoured plan* shows the system on which the distributing mains and piping are laid. The diameters of the pipes were determined by calculation, Hawksley's formula being used. The mains are composed of cast-iron socket pipes with turned spigots and sockets, and are laid as much as possible in trenches 1½ feet below the surface of the ground. The main from the high level reservoir commences with a diameter of 4 inches, which is gradually reduced to 3 inches. The diameter of the main from the low level reservoir is 5 inches reduced to 3 inches. The supply to the several buildings is delivered from the mains by wrought-iron screwed piping, of diameter 2 inches diminishing to 1 inch, and from this piping the water is drawn by cast-iron galvanized plug taps.

The mains end in "wash out" valves; and the supply to each building can be cut off or regulated by valves on the branches and mains.

It may be noted that brass taps and lead piping originally fixed in this system were found unsuitable, as these fittings were frequently stolen by the natives employed at the barracks. "Spring careless" taps and screw "waste not" taps were also tried and found unsuitable. A plain cast-iron plug tap, or bib cock, appears the best pattern for use in barracks.

The cost of the south water system was Rs. 85,060. The monthly cost of working is Rs. 380.

North Water supply.—The other system, known as the north water

* Not published.

supply, is almost precisely similar in design to the south water supply, but on a much larger scale, inasmuch as it has to supply

1 Regiment Cavalry,

4 Batteries Royal Artillery,

1 Regiment Infantry (except hospital).

The contoured plan will show the positions of the main well, service reservoirs, mains and piping, and that of a supplementary source of supply from an old well in the Cavalry Lines, known as the quarter-guard well. This supplementary supply was included in the system while the project was being worked out, and practically most of the supply for the Cavalry regiment is drawn from this source. The quarter-guard well system has been connected with that of the main well, so that the Artillery and Infantry can also be supplied from the quarter-guard well for a few days, should it be necessary to close the main well for repairs or cleaning out.

Machinery.—The pumps and engines at the main well are of the same pattern as those now at use at the south water supply. There are three engines and pumps of this pattern at the main well, or five sets in the north and south water supply together. The parts are interchangeable, and a reserve of spare working parts kept in store, so that in case of damage, repairs can be effected without any delay. Two sets of pumps worked at the same time can deliver about 10,000 gallons per hour in the reservoirs.

The machinery at the quarter-guard well consists of a pair of traction engines, which were used during the construction of the new barracks but are no longer required for that purpose. The engines have been dismounted and fixed in a small engine house. Each drives a treble barrel force pump (of pattern shown on page F-9 of Tangye and Holman's catalogue) by means of a belt from the fly-wheel of the engine to a pulley on the crank shaft of the pump. The machinery works well, and each set delivers about 3,000 gallons per hour.

Dimensions of the engine and pump are as follows:—

	Inches.
Diameter of cylinder, ...	10
Length of stroke, ...	12
Diameter of pump barrel, ...	3
" " suction pipe, ...	3
" " delivery main, ...	3
" " " "	4

Maximum steam pressure 50 lbs.

Reservoirs—Are solid masonry raised on arches and covered with light iron roof, and are very convenient and serviceable.

Delivery and Distributing Mains and Pipes—Are of the same description as those in the south water supply. The requisite diameters were calculated by Hawksley's formula, and the flow in the pipes is all that can be desired.

There is no stand pipe in this system—except an air vent in the connecting main between the two wells which crosses a ridge—the delivery main to the highest reservoir being always kept open. This main acts as a stand pipe.

The cost of the north water supply system was Rs. 2,27,852. The monthly working cost Rs. 500.

General remarks applicable to both systems.—At each pumping station there is an enclosure with a high wall and strong gate, necessary to keep soldiers and natives from approaching the wells and machinery. Each enclosure contains the following buildings:—

1. Engine house.
2. Quarters for engine driver.
3. Shed for fuel (corrugated iron on pillars).
4. Small shed for ashes.

At the north water supply, quarters for the native establishment have also been provided outside the enclosures. This is a convenient arrangement, and unobjectionable so long as the cleanliness of the ground around the quarters is insisted on. To help to this end, latrines, known as Crawford's rural privies, and rubbish receptacles have been provided with good effect.

At the north water supply well also, the open tops of the wells are protected with wire netting to keep out birds, leaves, &c., and this seems a desirable arrangement.

The efficiency of the working depends much on the quality and dryness of this fuel, but in these respects the fuel is generally satisfactory; and experiment has proved that at Secunderabad wood fuel is considerably cheaper than coal for use in stationary engines.

The monthly cost of working of the water supply is nearly the same as the saving on account of regimental water supply establishment, dispensed with on the completion of the steam water supply. But probably the quantity of the present supply is several times greater than that of the former, while, without any doubt, the present supply is more certain and more pure.

To the cost of mere working, however, it is fair to add the following annual charge in considering the financial result of the steam water supply :—

	Rs.
Interest at 4 per cent. on Rs. 3,12,000, the total cost, ...	12,480
Deterioration at 3 per cent. on Rs. 1,75,000, the approximate cost of piping and machinery, ...	5,250
Occasional and petty repairs, say, ...	700
Total, ...	18,430

Statement showing cost of Reservoirs and of 1000 *gallons of cubic contents and of daily supply.*

Name of Reservoir.	Cubic content being 3 days' supply.	Cost of Reservoir.	Cost for 1000 gallons of cubic contents.	Cost for 1000 gallons of daily supply.	Height of delivery above mean water level in well.
	Gallons.	Rs.	Rs.	Rs.	
South Water Supply.					
High level, ...	6,080 × 3 = 18,240	Not known	Not known	Not known	130
Low level, ...	18,080 × 3 = 54,240	Do.	Do.	Do.	85
North Water Supply.					
Cavalry officers, ...	2,400 × 3 = 7,200	2,566	356	1,069	139
Cavalry barracks, ...	9,504 × 3 = 28,512	5,801	203	610	104
Royal Artillery & Infantry officers,	5,600 × 3 = 16,800	4,881	291	873	67
Royal Artillery barracks, ...	10,800 × 3 = 32,400	5,151	159	478	81
Infantry barracks, ...	18,240 × 3 = 54,720	8,714	159	478	67

SECUNDERABAD,
3rd February, 1880.

H. C. F.