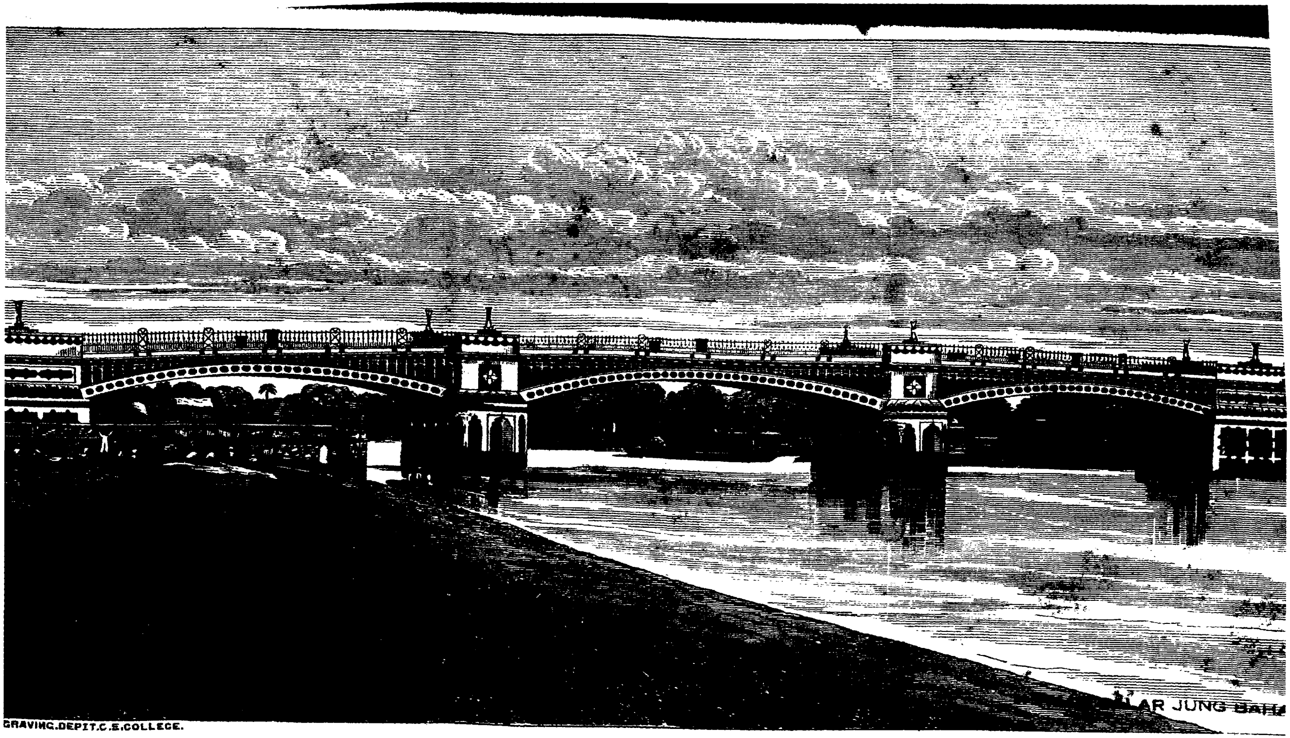

IRON BRIDGE OVER THE GOOMTEE-LUCKNOW.

PROFESSIONAL PAPERS

INDIAN ENGINEERING.

VOL. III.—1866.

EDITED BY

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PREFACE TO VOL. III.

On the completion of a Third Volume of these papers, I have again to offer my best acknowledgments to Contributors and Subscribers. The quantity of original matter in the present volume has been increased, the same care has been exercised in the selection and abridgment of Official and other papers, and I am glad to say there is every prospect of the Fourth Volume being as satisfactorily filled as its predecessor.

The History of the Great Trigonometrical Survey is concluded in the present Number, having now been brought up to the date of the published Annual Reports. In its compilation I have been largely indebted to Mr. Harry Duhan, for his valuable assistance in abridging the voluminous MS. reports in the Head Office; and to the present Superintendent of the Survey (Lieut.-Col. Walker, R.E.,) for his permission to make these extracts. As this series of papers has excited great interest, I propose shortly to publish them in a separate volume and perhaps to add some further illustrations.

No. 14, being the first Quarterly Number of Vol. IV., will be issued on 1st February next.

The price for Vol. IV. for 1867 will be as before, Rs. 14, if paid by 1st January next; *after* that date, Rs. 16, or Rs 4 for each Quarterly Number.

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J. G.

INDEX TO VOL. III.

LIST OF PLATES.

PHOTOGRAPHS.

ENGRAVINGS.

PHOTO-ZINCOGRAPHS.

LITHOGRAPHS.

PROFESSIONAL PAPERS ON INDIAN ENGINEERING.

No. XCIII.

THE TONSE BRIDGE.

Description of the Bridge over the River Tonse, erected for the East Indian Railway Co., near Allahabad, with particulars of its Mode of Construction. BY GEO. BROADRICK, ESQ., *Resident Engineer, East India Railway.*

THE main line of the East Indian Railway arrives, at a distance of 18 miles east of the river Jumna and of about 21 from Allahabad, at the river Tonse, which rises in Rewah or the adjoining districts, to the south-west, and after a course of about 120 miles flows into the Ganges at the village of Punassah. The railway is carried across it at about 4 miles above this village, measured along the course of the stream, which is very tortuous.

At the point of crossing, the *banks* present a tolerably equal amount of inclination to the bed, that on the west being about 10 feet lower than that on the east, and being overflowed in ordinary floods.

These banks and the bed of the river consist of fine dark gray river silt, of a sandy nature, and having occasional thin beds of very pure sand, the silt containing also a good deal of kunkur, and being overlaid by 18 or 20 feet of vegetable or alluvial soil. A bed of rock of the old red sandstone formation, and having its strata much disturbed and shattered, occurs 5 miles above the bridge, and above this point the river flows through a rocky country.

At the point of crossing, the *River* is about 1,000 feet wide at ordinary flood level, but from February to the setting-in of the rains, its thread of water is fordable, and not above 70 feet wide. From the highest point of the banks at the site of the bridge, to the lowest point of the botto of the actual river channel, is about 57 feet, the average depth of th channel being about 49 feet.

So wide and deep a channel implies the fact of the descent of a gre volume of water at certain periods, and accordingly we find that the flood due to the discharge of the area drained by the river, rise to the heigh of 30 feet above the low water level, and descend with great rapidit frequently as much as 7 miles per hour. In May 1856, the river ros 25 feet in 4½ hours.

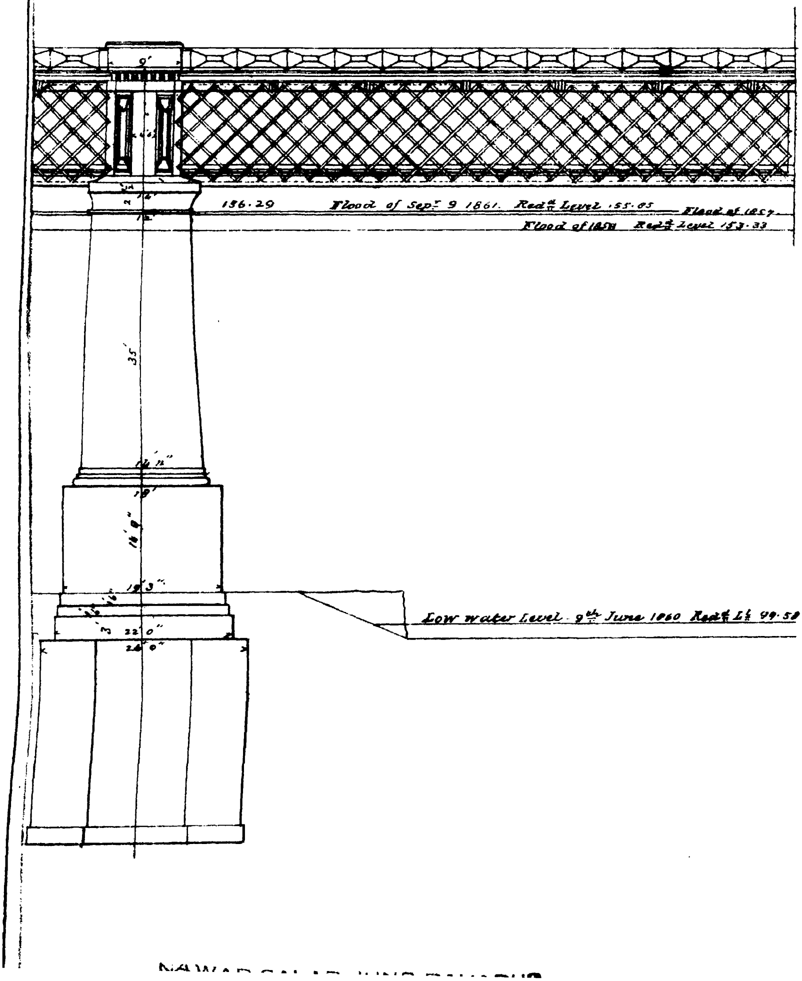
The height of the water in the rains, however, occasionally reaches 5 feet, and for a great part of the period between July and the middle o September, the surface is above the height due to local floods. This i caused by the water of the Ganges "backing-up" from that river, whicl it does to a distance of 12 or 14 miles above the bridge; at such season the surface is stagnant, and very favorable for some operations connecte with bridge building.

The local floods run with a volume of water that occupies the *whol* channel below their surface, so that the waterway is little more than tha necessary to discharge the floods at a considerable speed, there being hardly any "slack-water" at the sides. Therefore it was most desirable that the channel should be obstructed as little as possible by the proposed bridge.

This consideration as well as the great rise that would have been required for arches, rendered it necessary to adopt the *Girder* form of bridge. This was further rendered necessary by the fact that it was exceedingly doubtful whether all the arches could have been turned in one season, and whether a centering left to support the last arch, if not so turned, would have resisted the floods, unless most expensively designed and constructed. It must be borne in mind that Indian rivers which have been crossed on arched bridges, have usually been, if wide, *shallow*, thus rendering it considerably easier to leave the centres under an arch during the rains.

The abutments also must have been much more massive, if designed for a bridge of arches, than those of the present bridge, which merely carry a vertically acting load.

The use of the girder form of span also allowed of a road-bridge being combined with a railway bridge at a minimum expense, and in my opinion every bridge carrying a railway over a large river in India ought also to



9'
136·29
Flood of Sepr 9 1861. Redd Level 155·05
Flood of 1857
Flood of 1858 Redd Level 153·33
35'
14' 11"
18'
14' 9"
19' 3"
22' 0"
24' 0"
Low water Level 9th June 1860 Redd Ll 99·58

carry a road passable for vehicles of all kinds; a great number of crossings would thus be obtained at little greater cost than that required to carry over the railway only, the great expense being usually in foundations. The tolls on such bridges would probable yield a good dividend on the small extra cost required to provide the extra road.

The girder form of bridge having been decided on, the question of the design of the bridge became confined to the best form of span, of foundations, and width of waterway.

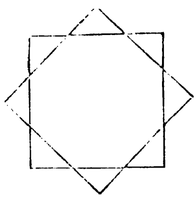
The lattice-girder was selected by Mr. Rendel, the Consulting Engineer to the Company in England, and the ironwork of the bridge, weighing about 1,200 tons, was constructed by the firm of Westwood, Baillie Campbell and Co., of Millwall. The spans adopted were 150 feet, and the thickness of piers was reduced to a minimum, being 12 feet only at the narrowest part.

Several experiments were made by order of Mr. Purser, at that time Chief Engineer of the N. W. Provinces division of the railway, in the driving of piles in the Tonse, but from considerations of the uncertainty of the supply of timber and of its durability in this country, the plan of building on wells was finally decided on for foundations.

The bridge was commenced on 1st November 1858, by Mr. Campbell, who previous to his resignation of the Company's service commenced four piers out of the six in the bridge.

Each pier rests on twelve *Wells*, of which ten are of 12 feet external diameter, and are arranged in the form of a parallelogram, while the two others, of 10 feet diameter, are situated at the ends or "noses" of the piers to carry the cut-waters. The steining of the wells is 3 feet 3 inches thick, built on curbs composed of radial slabs of timber 6 inches thick, confined in place by two square frames of sál timber, fixed as in the sketch in the margin, and bolted through each intersection; the slabs being likewise dowelled. The slabs were of the trees grown in the adjoining country. The curbs were further provided with upright suspending bolts, built into the steining which was of brickwork. The wells could in few instances be sunk more than 5 or 6 feet without recourse to the *jham* as the work was below the low water level of the river. The jhams were

Fig. 1.



wrought by windlasses with simple capstan-bar arms, made on the spot; the jhams were of iron throughout, and suspended by $\frac{3}{8}$-inch chains.

The sinking of the wells proved tedious and difficult, owing principally to the fact of their being sunk, not through sand, (the soil for which this description of foundation is adapted), but through a silt having the consistency of a light clay with no power of running in under the curb, and binding very hard against the brick cylinders. The running in of sand under the curb of a well, though frequently a great disadvantage, is perhaps a less evil than the formation of large hollows under the curb, into which part of the steining may fall after breaking off from the remainder. There was often a space of 6 feet in height under the curbs of the wells of the Tonse bridge, into which the cylinder sometimes slipped 2 or 3 feet at once, after remaining motionless for weeks in spite of loads of brickwork of 100 or 150 tons weight applied on the top in addition to 20 or 25 feet of steining. Clay likewise hangs under the curbs, and does not fall forward into the centre of the well so as to enable the jhams to bring it up, as is the case with sand.

The rate of progress was slow, the general result of the sinking on the whole of the ninety-three wells in the bridge, having been a little over 1 foot per well per month of the working season. The whole of the well sinking occupied four years and two months, of which twenty-seven months were lost by floods and other causes, of which one of the principal was the time required to clear out twice a depth of 20 feet of slush, which had accumulated during the rains of 1861 and 1862, over the wells of the east abutment. This cost from 10 to 15 rupees per 1,000 cubic feet for removal, as it was semifluid.

It must not be supposed however that all the foundations were sunk simultaneously. The piers were commenced in such order, and at such intervals of time as circumstances permitted, the above-named result of about 1 foot per well per month was the result as affected by every circumstance, except the grand one of the yearly floods. The piers were being built, and the girders were being erected, simultaneously with the well sinking, before the actual termination of which, two-thirds of the entire work of construction of the bridge had been completed.

Some difficulty was experienced with the foundations of piers No. 4 and No. 5. In the former two wells fell over on their sides in the flood of 1859, and lay in a hole of 7 or 8 feet in depth, which had been scoured around them. As we were badly off for pumps or any efficient means of removing the water, the process of extraction of the fallen cylinders was very slow; the brickwork, though only put together about a year previously, was so hard as to require to be blasted for its removal, and the curb and lower part of the cylinder remaining under water, was dragged out by main force; new wells were then sunk in the place of those extracted.

Difficulty was also experienced with the fifth pier, the wells in which fell inwards till the jham would not hang clear of the side of the bore. By applying the jham outside the wells till the curbs in some instances had been reached, and loading the wells with 50 to 100 tons of brickwork on the higher sides, about half the wells were so far brought upright that they were sunk nearly home; the others however threatened to delay the completion of the whole bridge to such an extent, that though the wells were much out of perpendicular, and not down by several feet to the required depth, it was determined to build the pier on them. They were therefore enclosed in a sheet piling of whole balks of creosoted Baltic fir a foot square, and driven down to the level to which the wells should have reached; these piles were secured at top by a double half timber waling tied through the pier with iron rods or chains with screw ends. The wells were then all cut off to a depth of nearly 10 feet below the low water level of the river, and united by a mass of brickwork 7 feet thick, covering the whole area of the foundation; the space between which and the sheet piling was filled up with rubble stone. While cutting off the wells, &c., the water was kept down by a force of 600 coolies, baling with the baskets used for irrigation, assisted by an Appold's pump, driven by steam power, for part of the time. The pile driving was successful, as the soil was favorable for the operation; the rams weighed 18 cwt., and the piles did not descend above $\frac{1}{4}$-inch for each blow of a 15 to 20 feet fall of ram.

It was at first proposed to staunch the wells so as to build up the hearting with brickwork, and for this purpose wooden platforms loaded with brickwork were lowered down to the bottoms, and the space between them and the interior of the well was caulked with wooden wedges payed with hemp and tallow, which were driven by a man wearing Siébe's diving-dress, in the use of which several of our bricklayers speedily became expert. The platforms being fixed, it was attempted to *bale* the wells dry. This, however, met with but partial success, and in all cases whe the well was dried, it was built up solid.

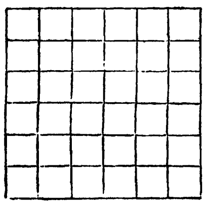
I found this plan, however, uncertain and expensive, and also that th lime set very well under water, which induced use me to fill the well up solid with concrete; this was composed of—

Lime (screened) per cent., ...	25
Brickbats, pucka but not jamah, broken to pass through a 2-inch ring, ...	50
Soorkhee (unscreened), ...	25
Per cent, ...	100

The concrete was sent down in buckets, which were upset at the bottom of the well, and which were passed through the interstices of a frame of bamboos laid over the wells' mouth, as in sketch (Fig. 2).

This frame was turned round one-quarter of a revolution at the lowering of each bucket, so as to ensure the even distribution of the concrete over the area of the bore of the well; when a certain number of buckets had been counted into the well, the concrete was rammed for half an hour with the end of a heavy sál spar, then another layer inserted, and so on, till the low water level of the river had been reached.

Fig. 2.



The wells being filled up, the temporary brickwork which had been added to raise the jhams above the water surface of the river was removed, the water being baled down for this purpose to 6 or 7 feet below the level of that in the river; the spaces between the wells were then cleared out about another foot lower, and levelled off. On these was placed a foot of packing of brickbats, and the brickwork of the wells was then corbelled over this packing till it met that of the adjoining well, and the foundation presented an unbroken floor of brickwork. It was desired to avoid vaulting over the intervening spaces to obviate lateral thrust. A mass of solid brickwork, 3 feet thick, was then built all over the floor abovementioned, which brought the work up to low water level: the ends of this mass were faced with ashlar.

I may mention, in passing, that bricks which had been burnt to a black color and spongy texture, though exceedingly hard, were subject to a decomposition, probably by the rusting of the black oxide of iron in them, and had to be excluded from work which was to remain constantly under water. This may, of course, have been a peculiarity of the clay of the locality, and I have not heard of its having been noticed elsewhere.

The *Piers* were built according to the general drawing accompanying; the cutwaters up to the base moulding were faced with heavy ashlar, in courses of about 18 inches thick, with drafted edges, and picked down between them. The average local floods rise to about the height of the base moulding, and as there is usually no rapid flood of any duration above this level, and stonework at the Tonse was very costly, the original proposal to face the cutwaters with it for their whole height was given up.

Attempts were of course made to obtain the *stone* from the rocky country mentioned as occurring not far above the bridge. A large area of country was examined, and more than one trial quarry opened. A considerable quantity of stone was got at a place called Soolmaiee, 9 miles by water from the bridge, the quarry being on the river bank, and being stated to have been the one whence a good deal of stone was obtained to build the neighbouring fort of Khyragurh, now in ruins. Marks of ancient quarrying are visible below the present low water level of the river and under water. Totally unlike that in the immediate neighbourhood, however, this stone proved so friable and soft that it could hardly be worked to an arris, and could be used only in parts of the bridge *not* much exposed to wear, or of lesser consequence, as the filling in of the caps of the piers. The cost of "baring" this quarry was also very great, owing to the shattered state of the strata, which were full of faults.

The Soolmaiee quarry having been abandoned, another was commenced inland, also about 9 miles from the bridge, on a hill above the village of Kohrar; here there was little expense for "baring" and better blocks could be obtained, though the beds so far as we worked them were but about 18 inches thick. The stone was of good color but turned out so *hard* that it could not be wrought without unreasonable expense, besides which the carriage over a most wretched district kucha road was very costly. Some of the stone from this quarry was, I believe, used in the Cawnpore Memorial, owing to its matching the remainder in color.

A large quantity of rubble was obtained about 5 miles above the bridge, but of very inferior quality, though hard and durable as granite.

The greater part of the ashlar was finally obtained from Chunar; that for the cutwaters of four piers was supplied ready wrought by Mr. Carter, then a stone dealer there, and having been prepared under the superintendence of a practical English mason, was in every respect most satisfactory. It was sent up to the Tonse by water, and here I may state that one of our most annoying hindrances in building the bridge was the want of depth at the mouth of the river. A bar extends across it on which there is not above a foot of water in April and May. Many of the boats were of course unable to pass it, and their cargoes had to be discharged at the village of Sursah, on the Ganges, and brought on in other boats during the rains.

By erecting stages of bamboos in the water, on each of which about 50 coolies were placed with phourahs, having long handles for clearing away the mud, and at the same time narrowing the channel with low embankments, so as to throw a stronger stream through the parts where the mud was being agitated, the channel was usually kept open in the dry season for boats of 200 maunds burden, though it frequently required from 12 to 20 men at the towing line to get them past the obstruction. The bar at the mouth of the Tonse moreover held up the water at the works and added a good deal to the expense of getting in the foundations of the bridge.

The rest of the ashlar was obtained from the quarries on the Jumna and from Mirzapore, and wrought on the works.

The *Bricks* were made at the village of Kuthoulee, about a mile and a half from the bridge. Here a brick yard of 50 acres was established, working 20 large kilns. Some of these were of the kind known as the "Roorkee" kiln, in which the bricks are placed on arches having slits, through which the heat ascends. The out-turn of bricks from these was an average one, but they were given up owing to the expense and delay of rebuilding the arches which fell in at every burning.

The "flame-kiln," in which the wood is placed in flues among the bricks to be burnt, and also burnt in "chulahs," or ovens built of the same, and running under the mass, was the form found to answer best. The fuel was usually wood, but charcoal was used to a limited extent, and with excellent results. The average out-turns were 70 per cent. of fair bricks, but only 44 per cent. were as a rule permitted to be used in the bridge, the rest being used in building a station on the line.

Wood cost Rs. 28 per 100 maunds, and the cost of the bricks was from 11 to 16 per 1,000 bricks of first class quality and of English dimensions. They were crushed with a load of about 600 lbs. on a cubic inch, being by no means of a hard description.

The *Lime* was burnt in kilns, and made from swept up kunkur; no ooplah (or kundah) or fuel inferior to wood was allowed to be used in burning it. It was almost of a pure white color, and cost Rs. 20 per 100 cubic feet; it was considerably hydraulic. It was used in equal quantities with soorkhee, and the ingredients of the mortar were screened through an iron sieve of ¼-inch spaces. Owing to the care bestowed on the screening, no grinding was necessary for mixing the mortar, which was done in "tagars," or brick troughs with rakes or phourahs.

In erecting most of the piers no scaffolding was employed, except a sloping stage of 60 feet in height, up which all the materials were carried. The rate of progress was 1 foot to 1 foot 6 inches in height of the pier per diem; the work being done by day labor, which was found, when well superintended by an European, to be cheaper than contract brickwork.

The *Abutments* of the bridge were built in pits of some 50 feet in depth, as they stand well back into the river banks. Considerable trouble was experienced with the western pit, from the falling in of the black silt which forms the greater part of the sides. A very extensive slip took place in 1860, filling up one-fourth of the depth of the pit. This took place on the day after 500 coolies had been removed from work in it. The mass came down with great violence, and without warning, the sides being at the time sloped to 1 to 1.

The greater part of the work in excavating these pits was paid for in cowries, a very expeditious method of working, and one much liked by the people. The earth was "got" and "filled" by daywork beldars, and removed by the cowrie people. So well were the former kept up to their work by the latter, that 200 cubic feet per diem per man were frequently "got" in a damp sticky soil.

The cost of the excavation was from Rs. 3 to 7 per 1,000 cubic feet, except for removing slush; the "lift" being from 10 to 90 feet, and the "lead" 50 to 200 feet. In some cases there was as much as 1,400 feet lead, and in these I tried the plan of laying temporary rails and running the earth out on English-made tip wagons pushed by coolies; owing to the shortness of the run, and to the fact of my having been obliged to use the permanent-way material for the road, as well as the imperfect "tip" that happened to be available, no reduction in cost below that of doing the same work by coolies was effected, though I have little doubt but that in cases where labor is scarce and the lead long, properly constructed wagons could be used with much economy; without a proper "tip," however, the lead must be very long to make it worth while to employ them.

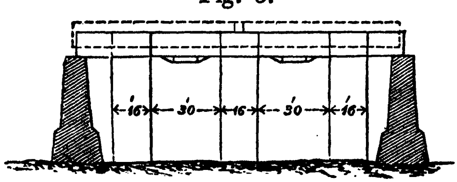
The *Plant* for the whole works, exclusive of brick yard arrangements, consisted of 24 lime kilns; 9 English fashion smiths' forges; a sawpit of English fashion also, and covered in; a carpenters' shop of 95 feet in length; a lime store of about 3,000 square feet area; 3 moulding floors for carpentry and masonry; shed for 40 bullocks; and a temporary bridge over the river of three spans of 20 feet each, with ghâts and road over it, besides the plant specially used for erecting the ironwork. About 30 acres of ground were occupied by the works, plant, and materials, exclusive of the actual river bed.

The *Ironwork* of the bridge began to arrive in 1861, it was all brought up by steamers from Calcutta. The first cargo of some 400 tons was delivered at the site of the bridge about October of that year. The passage of the first steamer up the Tonse was an event for the neighbouring population, crowds of whom assembled on the banks as the vessel and her two heavily laden flats passed up.

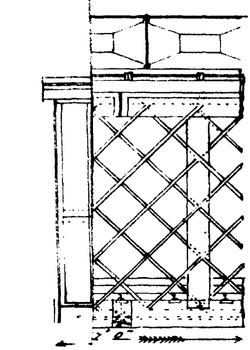
A large portion however of the cargoes of the steamers had to be discharged on the banks of the Ganges owing to want of water at the mouth of the Tonse; it was brought up to the works on country boats. More than one piece fell overboard during the operation, one weighing a ton, in 12 feet water in the Ganges, which was recovered by tackle hooked on by native divers. No crane was used in unloading the 1,200 tons of iron in the bridge, every piece having been carried on shore by hand.

The ironwork was erected on a double row of wedges supported by a scaffolding of sawn timber, consisting for each span, of trestles about 60 feet in height, an elevation of which is subjoined; these trestles carried six double rows of whole timber balks as longitudinals, the trestles being arranged in pairs, as shown in (Fig. 3), in which the outline of the girder is represented by the dotted lines.

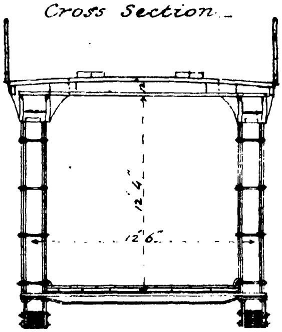
Fig. 3.



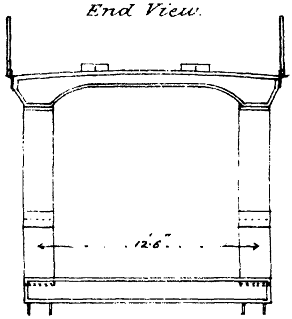
At the level of the top of the piers were four rows of longitudinals, the



Cross Section.



End View.



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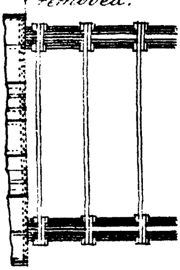
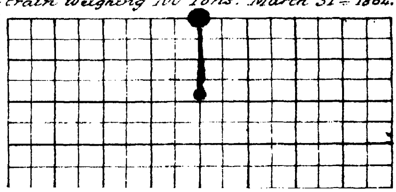


Diagram showing deflection of No. 5 Span of Tonse Bridge, taken during the passage of a train weighing 100 Tons. March 31st 1864.



outermost pair of which carried a line of rails on which worked a travelling crane striding across the girder. The inner pair of longitudinals at the lower level carried the tension links of the girder, and the upper pair of longitudinals carried the compression member, or "top-boxes."

The *trestles* were, in the first two spans erected, supported by piles of sál timber, as shown in the drawing, but all the spans besides were erected on stages resting on a row of about 60 sleepers under each sill. The thread of the stream runs through No. 2 span (reckoning from east to west), and it was consequently necessary to fill this channel up and divert the river through an artificial cut of 70 feet wide, passing under one of the spans already completed, a new temporary bridge being erected over the cut for conveying the supply of materials. As it was desirable to save time, the sleepers were laid on the earth as soon as it was filled into the natural channel, and while it was in a state to barely support the weight of the coolies who filled it in. A bed of 18 inches of dry sand was placed under the sleepers, which were beaten down with heavy mauls before the sills of the stage were laid. I tested a certain number of the sleepers with a weight of rails greater per foot square, than that which they would have to support when under their greatest burden, and was gratified to find that they did not sink above 3 inches. In fact the greatest extent to which they sunk under the weight of the stage and girder, was 2 inches only. The sleepers were ordinary railway sleepers. The stages were erected with derricks, of which I had five, each of 75 feet or more in height, working two on each side of the stage, the fifth being much stronger and capable of hoisting 4 tons to a height of 80 feet. This derrick was in its practical details designed by my foreman carpenter, and proved very efficient, the great difficulty being in raising it on end. This was done by two tackles acting from the top of one of the piers and secured to the derrick at one-third of the length from its upper end. These tackles consisted of a pair of two sheaved blocks with double purchase crabs on the falls.

The larger derrick was used for sending up the longitudinals of the stage, the travelling crane, the stones, weighing 274 tons each, on which the bed plates of the girders rested, and the heavier parts of the girders themselves. The guys were secured to piles 15 feet long, driven into the river bed where required. The smaller timbers of the stage were sent up "by the run," *i. e.*, by a gang of men running away with the falls of the tackles, which was a much quicker method than using crabs, though I would not recommend it except in cases where it is extremely desirable to save time. About three weeks were required to erect the stage for one span. The longitudinals immediately under the tension-links over the 30 feet bays, were strengthened by trusses (shown in Fig. 3) of wrought-iron with cast-iron saddles. These had been tested up to 19 tons for each longitudinal of 24 inches by 12 inches, and were thus amply strong to carry the portion of the weight of the girder imposed on them previously to its completion.

The girders rested on sleepers of Baltic fir, or sál, under which were folding wedges of 3 feet long, the camber or upward curve being given to the girder by additional wooden packings of different thicknesses under the wedges.

The spaces between the longitudinals were covered with the iron flooring plates, to be used in the upper roadway, so as to form a continuous platform from pier to pier. Several fatal falls from the stages having taken place among the workpeople, I had a net of ropes with meshes about 1 foot square suspended from the under surface of the flooring of one span. I was obliged to abandon this, however, when the rivetting commenced, owing to the danger of fire. Each frame of the spans was put together on a plaster floor on the river bank, and each piece numbered similarly on each side of one of the joints, so that when the frames were taken apart for removal into the river bed, they might readily be selected. When the girder was able to stand alone, the stages were pulled down by the derricks used in their erection, the demolition of each stage occupying only about eight days. A large quantity of "cheer" timber from the Himalayas was used in the staging; it much resembled white Swedish pine, and was rather a spongy sappy wood, not likely to be very durable. It was no doubt in an unseasoned state, which may partly account for the above defects. The rest of the stages was either of round sál spars, or squared Baltic or American fir.

As the details of the *Girders* may not be very easily discernible from the drawings which I have been able to furnish, a general description of them may be useful in enabling the reader to understand the method of their erection.

They consist, like all framed girders, of parts constructed to resist compression at the top, and of a set of struts, which from their inclination convey the weight of the girder and load, from the top member towards the piers, the vertical part of this stress being again transmitted by a set of tension bars from the lower to the upper member, again removed by the next set of struts a stage further towards the piers, and so on to the last struts, which bear against strong upright columns of boiler-plate on the tubular or "box" principle. As the strain on the struts and ties increases from the centre of the girder towards the ends, their scantling is gradually increased, there being four classes of these bars in each span.

The struts and ties intersect each other at right angles, thus forming a lattice wall of which the top-boxes may be called the coping, and the chain of links securing the struts from parting at foot, may be called the foundation.

Two pairs of such walls make up one span, a floor being laid at the bottom of the walls to carry the carriage-road, and another overhead to carry the railway. The lower member, by which the bottoms of the struts are tied together, consists of a double layer of flat bars or links placed on edge and united by bolts with each other, and with outer plates to which the struts and ties are rivetted. These links are not flexible like a chain, but have their ends rigidly connected by the bolts. This double line of links increases in strength from the ends to the centre of the girder, the number of links being greatest at the centre, and at the ends reduced to merely the two outside plates carrying the lattice bars. The lattices are strengthened transversely by a bracing inserted between the walls which form the sides of the span and which are marked *ww* in the marginal sketch (Fig. 4). In this sketch the bracing, which is of a zigzag form, is indicated; RY is the railway, *cc* the compression member or "top-boxes," TT the tension links or lower member, RD the road, and *ww* the walls of lattice work, or "webs" of the girder. The bars composing these webs or walls are of the "channel" section, (marginal sketch, Fig. 5,) rivetted back to back at the intersections. The top boxes are simply boxes of boiler-plates, increasing in strength from the ends to the centre, and secured together by flanges rivetted with inch rivets; the ends of the boxes and the flanges are planed to ensure a good butt.

Fig. 4.

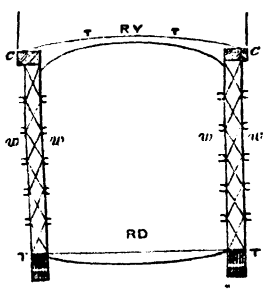
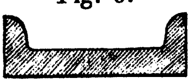


Fig. 5.

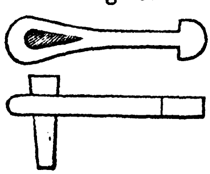


The girders rest on blocks of cast-iron hollowed out underneath, and bolted to the bottoms of the "end standards" or vertical boxes. These blocks rest on "saddles" of cast-iron fixed at one end of the girder, so as to admit of a movement there in a circular or vertical direction only, while at the other end of the girder the saddles run loosely on cast-iron rollers, working on planed surfaces, so as to admit of a horizontal movement during expansion and contraction under changes of atmospheric temperature, as well as of a circular vertical movement to compensate the deflection arising from loads on the girder. The maximum horizontal movement due to a high natural temperature is about 1½ inch, the greatest actual movement taking place when the nights are cold; the girders expand in the hot weather to the full extent, and their length remains then unaltered till a decided change of weather sets in. Under a June sun the iron-work becomes heated to a degree that renders it difficult to keep the hand long upon it.

The ironwork of the westernmost, or of No. 7 span, was the first commenced. The parts had been carried into the river bed and laid under the staging during the erection of the stage, and on 24th March 1862, the first portion was sent up for erection. This was one of the central outside plates of the lower member, the whole of which was laid down as fast as the materials could be got up. The tension links were laid down to the camber and proper line, and temporarily connected by pins or "drifts" passed loosely through the holes; on removing these, the bolts *were substituted. These bolts are most important parts of the bridge, and ought to fit with the greatest accuracy. To prevent any bending of the bolts or damage to the screwed ends, they were driven in with* 10 lbs. copper headed hammers, or with ordinary sledges with a lead packing next to the bolts. These bolts are of the best Bowling-bridge iron, and very great care had been bestowed on their turning and finishing.

The lower member being completed, the central diaphrams were next got on end and secured in their places by colters. Of these little implements, represented in Fig. 6, several thousand were made to secure the parts of the bridge loosely together during erection, bolts being employed for the same purpose where greater accuracy was requisite. The centre "top box" was next sent up and temporarily secured, the others were then

Fig. 6.



added, resting on the cross beams of the stage; the vertical boxes or end standards were last got into place.

The framework or outline of the girder being thus completed, the lattice bars were got in and rivetted to the upper and lower members, the top boxes being simultaneously rivetted together with the iron beams carrying the roadway overhead.

A few of the iron joists of the lower roadway were coltered on to keep the girders steady, and a few colters put into the intersections of the lattice, one row of which on each side was also rivetted up. The girder was then ready for "launching" or lowering down on its bearings. This operation commonly took about 20 minutes, men being stationed at each pair of wedges, both above and below, to drive them back with sledge hammers. The levels of about six points had been previously observed with a spirit level, placed on one of the piers, and these were again read off when the whole of the wedges were clear of the girder, and the deflection in launching noted. The amount of this deflection or descent of the girder is in a great degree a test of the workmanship displayed in the manufacture of the parts, and more especially in the erection and rivetting up. It amounted on an average of the spans to $1\frac{3}{8}$-inch, its minimum was $\frac{5}{8}$-inch, and maximum $2\frac{1}{2}$ inches. The amount of camber, or upward curve, given to the spans, was from 3 to 5 inches, from which the descent in launching was a deduction. This remaining cambre was reduced further to one inch at the rail surface by adjusting it in the timber longitudinals of the road.

The girder being lowered upon its bearings, the stage was next pulled down, and re-erected for another span; three sets of staging, or a complete set for each of three spans, being used in erecting the seven spans of the bridge.

At the commencement of the rains in 1863, I avoided pulling down the travelling crane; which was placed on a low truck, running on a line of rails temporarily laid on the top of the spans, and blocked with timber so as to steady it. The stage was removed from beneath it, leaving the side frames suspended outside the girder. When required to be removed to another span, as there were no stages to carry it, it was transferred upon the truck along the girders already completed to the stage, which was ready to receive its wheels, for the erection of another span. The crane weighed 7 tons, and it was a considerable saving of time and expense to avoid taking it down and erecting it on the top of the new stage when the rains were over.

This crane was calculated to lift about 2 tons, and with it all the heavier parts of the girders were erected, except the bed-plates and end standards, which were sent up by the large derrick before-mentioned. The lighter parts were sent up "by the run" by means of tackles hooked on the work where convenient; besides which a considerable number of the parts were carried up a slope of bamboos erected to give access to the spans for the workpeople. Besides the above tackle, a small derrick standing in the lower roadway was found very convenient.

Ten or twelve sets of rivetters were employed in rivetting-up each span; each set consisting of four smiths. Portable forges were sent out from England for this work, but were speedily abandoned for the common native forge, in which a small plate of iron for the fire, and a hand-bellows is all the apparatus necessary, and which constitute a forge far more convenient to natives, than those on the English plan. For the *workshops*, however, the English forge is almost essential.

The most important of the other tools were screw jacks of from 5 to 12 tons' purchase, and powerful screw clamps for closing the bars of the lattice solidly together while rivetting.

The rivetters had been well trained at the Soane bridge, and were thoroughly accustomed to the work; the English rivetters being mainly employed in superintendence.

After the girders had been launched, they were completed during the rains. The upper floor is covered with iron plates, the lower with a double layer of diagonally laid sál planking caulked at the joints, and 5 inches in total thickness.

In the case of the last two spans erected, the stages and pier were carried up simultaneously, and a considerable portion of the girder, No. 6, was built on the stage before the pier had reached the level of the bottom of it, so that no time was lost in the erection of the pier and girders.

The average time of erecting a span from the laying down of the first plate to the "launching" was 28 days.

I made every endeavour to have the bridge ready for testing by February 22nd, 1864, and the greater part of the line of railway was laid by torchlight on the night of the 21st.

At 10 o'clock next morning, the first locomotive passed slowly over the bridge, and shortly afterwards returned at speed.

The bridge was tested next day by running a train weighing 200 tons over it at full speed, and observing the deflection produced by repeated passages. The maximum deflection noted was $\frac{9}{16}$-inch, and the side vibration was but $\frac{2}{16}$-inch, or almost nil. The girders sprung up to their original shape immediately after the train had passed them. The deflection was recorded by a pencil fixed to the lower part of one of the spans which was pressed by the hand against a graduated paper fixed on a firm basis independent of the span. The amount of descent of the pencil was checked by observing a point on the girder with a spirit level placed on the adjoining pier. I append a copy of one of these papers, showing the diagram resulting from the passage of a train weighing about 100 tons at 25 miles per hour.

The rails were fixed in the ordinary chairs, spiked to beams of fir or sál timber, bolted to the cross bearers of the span with four $\frac{5}{8}$-inch bolts at every intersection, and halved, but not secured together at the ends, play being allowed in the halving for the expansion of the girder. The rails were also cut to a half-lap joint at the ends, which was secured by the ordinary fish plates, having the bolt-holes slotted to allow of the rail and bolts advancing and retiring with changes of temperature.

When the fish plate bolts were screwed tight, the movement, which took place about an hour after sunset, was attended with rather a loud cracking sound, arising from the friction of the plates and rail, and the former became distinctly *magnetic* from the effect of friction.

There are two small spans formed of box girders of 24 feet in length, giving access to the lower roadway at the ends of the bridge, and covered with iron plates in continuation of those on the main spans. These box girders rest on expansion rollers sunk in the stones which carry them.

The spaces at the ends of the girders are concealed by porches of wrought Chunar stone, and there are entrances to the lower roadway in a similar style, which is an adaptation of Mussulman architecture, in a plain and massive form. No plastering is used in the bridge, all the brick-work being tuck-pointed with mortar burnt from a peculiar species of kunkur.

To the east, the bridge is approached by a curved embankment, containing 9 millions of cubic feet, chiefly thrown up by the contractors, Messrs.

Hunt and Elmsley in 1855. The river appears to have originally flowed through the low ground across which this heavy embankment extends.

The lattice girder appears peculiarly adapted for bridges over Indian rivers and for railway work in general, from the multiplication of its parts, which in a great measure obviates the effects of bad workmanship in erecting; an important thing, as rivetting done by natives of India is never so good as that done by Englishmen. A defective portion, moreover, can be removed and another inserted without detriment to the structure, which has the further advantage of being composed mainly of bars and not plates, which must be an element of durability. The parts of a lattice girder moreover are light and of manageable size, a great consideration in India.

I cannot conclude this notice of the bridge without mentioning that I did not erect the whole, and without remarking on the services rendered by my predecessors in charge of the works.

As before-mentioned, Mr. C. Campbell, now in the service of the Government of India, began the bridge; and also provided a large quantity of materials. He was succeeded by Mr. R. Hildebrand, who built one pier entirely, a portion of another, and carried out the great part of the tedious and difficult well foundations; while the porches and ornamental stonework of the bridge were finished by Mr. Brooks.

G. B.

No. XCIV.

WATER SUPPLY OF FORT WILLIAM.

Abridged from a Memorandum and Report, by CAPTAIN S. T. TREVOR, R.E., *Garrison Engineer, Calcutta.*

THIS scheme differs from the last, prepared by Major Sankey, R.E., in two important particulars, viz.:—(1), It is totally independent of the question of the drainage and sewage of the Fort; and (2), It is based upon a different source for the supply of water. The source of supply is to be the Havildar's tank, which is to be extended, and to have an additional tank dug alongside of it, to yield the necessary quantity.

The first questions to be settled, are the *Purity and Sufficiency of the Source.* Its purity is I believed, admitted by every body, so far, at all events as the present Havildar's tank is concerned; and it may be inferred, with tolerable safety, that the same conditions that cause the present tank to yield a pure supply, will also be applicable to any extensions that may be made of it.

As regards the sufficiency of the source on the other hand, I will proceed to show how that can be effected. In the first place, I will fix the quantity required for consumption, and then calculate the extension required to be made to the tank to yield that quantity.

I have obtained a copy of the last census taken of the residents in the fort. From this it appears that the resident and non-resident population of the fort, including women and children, is as follows:—

Resident.

	Souls.	
European troops, ...	1,271	
Native troops, ...	299	
Native establishment, ...	261	
Private servants, ...	268	
		2,099

Non-Resident.

Native establishments,	...	...	...	1,672
Private servants, ...	...	...	...	662
	Grand Total,	...	...	4,333

This census does not include the temporary increase annually, in the number of troops during the cold weather months. It may be assumed that for the four cold months, November to March, there is a constant additional force of about 1,600 men and 400 followers, either accommodated in the Fort, or encamped on the *maidan.*

I shall show presently that the supply of water during the four rainy months, June, July, August, and September, is comparatively unlimited, and that in calculating the volume to be stored, it is only necessary to consider the consumption of the eight months, October to May. Now the consumption during these eight months will be for the permanent resident and non-resident population of 4,333 souls for the whole time, and for 1,400 souls, in addition, during half the time, or it may be taken as for a permanent population of $(4{,}333 + \frac{1400}{2} =)$ 5,033, for the whole time. But it appears from the census, taking it in round numbers, that about half the population is resident, and the other half non-resident; and it may be safely assumed that the non-residents will consume at the outside only half the quantity of water that the residents will, as their cooking, bathing and washing are all done at their own houses. Therefore the number of souls, for whom a uniformly equal supply is required to be provided, may be taken at only three-fourths of the above number, *i. e.,* $(\frac{3}{4} \times 5{,}033) = 3{,}772$ souls.

I think it will be a sufficient allowance for contingencies, if the population be taken at 5,000 souls, in calculating the size of the reservoirs.

The next point for consideration is the *Supply per Head.* At page 744, of the 3rd volume of the *Aide Memoire,* it is stated that 4·4 gallons is the allowance in the calculations of French Engineers for each individual per day, but that this allowance is very small, although, even in English towns, the consumption per head per day of 24 hours does not exceed eight gallons. At page 746, it is stated, "that the quantity to be calculated for any given population may usually be reckoned at 20 gallons per

head per day, which will include all ordinary trade consumption they may require," and I have based my scheme on this calculation. From the foregoing it would appear that the proportion between the actual consumption and the whole allowance per head is 8 to 20 or 2 to 5, so that the 20 gallon supply, if regarded as for personal consumption only, would be equivalent to a *total* allowance of 50 gallons a day.

If it be admitted, then, that the supply to be stored is at the rate of 20 gallons a head for 5,000 persons, the next point to be considered is the *Collection of this Supply*, and the extent to which the Havildar's tank requires to be enlarged to hold it.

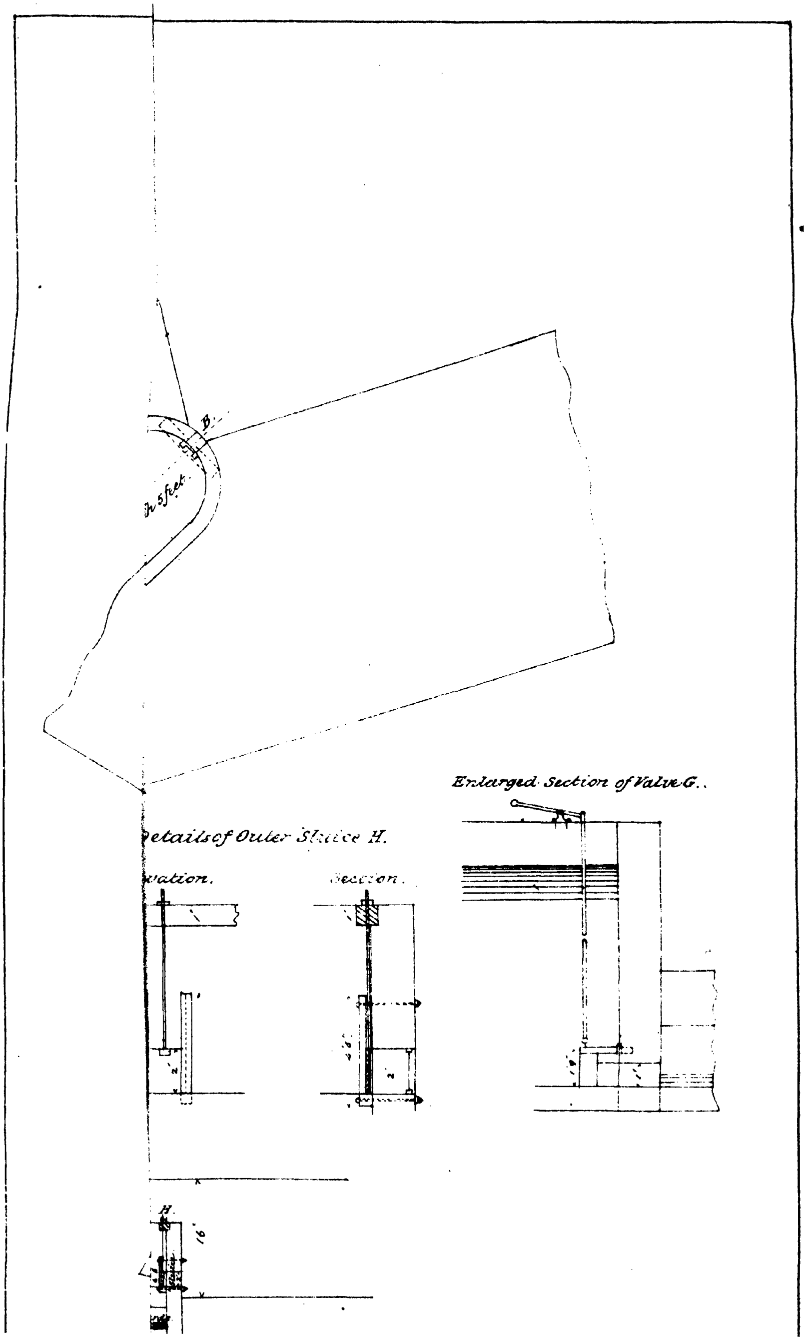
The collection is, of course, to be made entirely from the rain-fall. The average monthly rain-fall of Calcutta, deduced from the observations of 20 years, from 1839 to 1858, as given in Beardmore's Manual of Hydrology, page 330, is shown below. I have not been able to obtain any table of the monthly evaporation at Calcutta; but at page 335 of the book I have mentioned, a Table is given of the average monthly evaporation of Bombay, deduced from observations of five years, which will answer for all practical purposes, as the conditions of rain-fall and temperature at the two places are sufficiently similar. I have tabulated the monthly rain-fall and evaporation, and shown the difference between the two for corresponding months, calling those differences (*) in which the rain-fall exceeds the evaporation, and those (†) in which the evaporation exceeds the rain-fall. From this Table it will seen that only in the four months of June, July, August, and September, is there any effective rain-fall, and that in the remaining eight months, from October to May, the evaporation considerably exceeds the rain-fall. Adding the (*) quantities together, and (†) quantities together, it will be seen that the effective rain-fall of the year, compressed into four consecutive months, is equal to 33·69 inches, or at the rate of about one-fourth of an inch a day, and

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
Rain-fall, ..	0·59	0·62	1·31	2·39	5·38	11·50	13·61	15·00	10·77	4·90	0·52	0·29	66·89
Evaporation,	7·41	6·99	8·79	8·57	10·00	5·12	3·36	4·18	4·53	6·73	8·00	8·37	82·05
Difference, ..	6·82†	6·37†	7·48†	6·18†	4·62†	6·38*	10·25*	10·82*	6·24*	1·83†	7·28†	8·08†	..

the effective evaporation of the year, extending over the remaining eight months, is equal to 48·66 inches, or at the rate of $\frac{1}{5}$th of an inch a day.

Now it will be seen from Table 18, at page 63 of Beardmore's Manual of Hydrology, that a supply of 20 gallons per head per diem for a population of 5,000 is equivalent to a supply of 16,406 cubic feet per diem, or *11·14 cubic feet per minute.* And it will also be seen from Table 15, page 60, that this discharge of *11·14* cubic feet per minute, with a rain-fall of $\frac{1}{4}$th of an inch in 24 hours, may be obtained from an area of about 18 acres. The drainage from 18 acres will, therefore, yield the required daily supply during the four rainy months, June to September. But in addition to meeting the daily supply for these four months, it is required to collect a sufficient quantity to store up for the eight dry months, October to May, and therefore the discharge from at least three times the area required to yield the daily supply must be collected during the rains, with as much more as is requisite to meet the loss by evaporation, in order to have a sufficient supply stored up by the end of the rains to last through the dry months. The supply required for these eight dry months, equal to 243 days, at 16,406 cubic feet a day, is 3,986,658, or say four millions of cubic feet.

The Havildar's tank is from 16½ to 17 feet deep below surface of surrounding ground, and holds 14 feet of water when full to the point of overflowing. Allowing 4 feet of the depth of the water to meet the evaporation (shown above to be 48·66 inches for the whole eight dry months), the remaining 10 feet is the depth to be taken for calculating the size of the reservoir required to hold the four millions of cubic feet of water to be stored, assuming that the reservoir will be dug to the same depth as the Havildar's tank. The average area of this reservoir should therefore be 1000×400 feet. An excess of 25 per cent. will be sufficient for contingencies of unusually dry seasons, &c., and I think, if the new tanks, including the existing one, be made to have an aggregate capacity of $1000 \times 500 \times 14 = 7{,}000{,}000$ cubic feet, there will be no fear of the supply ever running short. For the collection of seven millions of cubic feet as eight months' store, a discharge of 40 cubic feet per minute must be collected during the four rainy months, in addition to the daily consumption of those months. To produce this discharge requires an area of 64 acres, with $\frac{1}{4}$-inch rain-fall per diem, so that the total minimum area to be drained into the new reservoirs must be $(64 + 18) = 82$ acres. From



B.
h 5 feet.
Enlarged Section of Valve G..
etails of Outer Sluice H.
vation.
Section.
H.
16"

my report on the drainage of the maidan, it will be seen that the extent of ground that can be drained into the tanks is 270 acres, or three times as much as is required.

I will now pass on to the question of the *Distribution of the Supply.* I propose to dip the end of the suction main into a well or reservoir, connected with both tanks by a filter on each side, and having sluice-valves as shown in the plate. The details of the filters will be apparent from the drawing. Each filter is 15 feet broad by 60 feet long, containing a filtering surface of 100 square yards. I anticipate that the rate of filtration will be about 1,000 gallons per square yard per diem, or 100,000 gallons from each filter. When the tank is full, it will not be possible to get at the surface of the sand to clean it, but this will be easy when the water falls below the level of the side walls of the filter. By shutting the outer sluice and letting the engine exhaust the water from the filter, the surface of the sand will be exposed, so that the deposit on it can be removed.

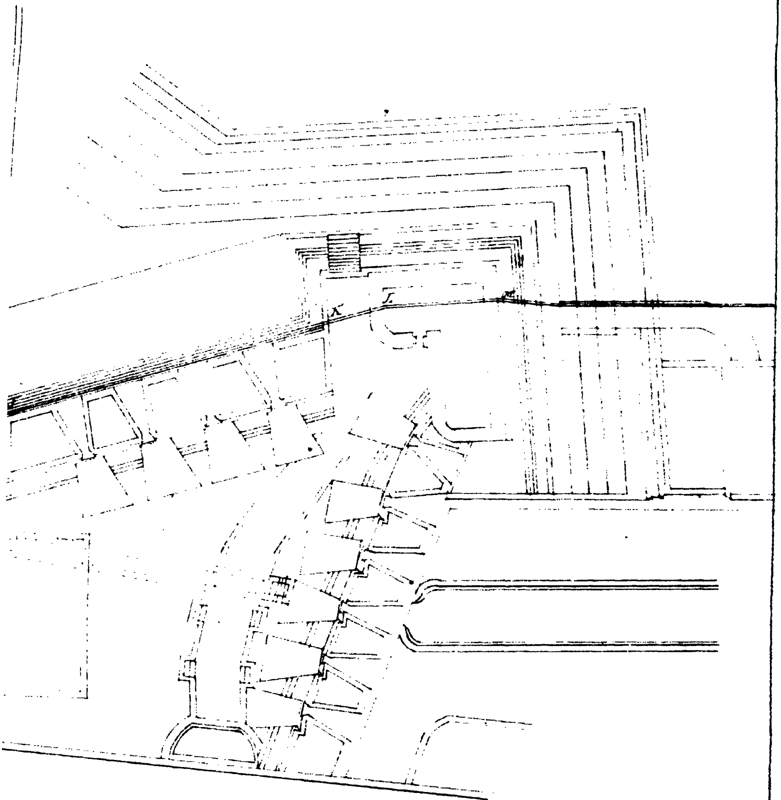
If the side walls are raised up at once to the highest level of the water, this could be done at all times, but I do not think such frequent cleansing will be necessary, and it is well not to incur the expense of raising the walls till it is shown to be required.

The Steam-Engine is placed in the redoubt of the left re-entering place of arms, treasury gate ravelin, which is the most convenient place I can find. I have brought the suction main on a level along the glacis as shown on the plan, and almost in a direct line from the filter to the engine. It is 3 feet under ground at the filter, and 11 feet at the crest of the glacis. From the engine the forcing main is carried almost in a straight line across the ditch, up the escarps of the King's Bastion, and along the right flank to the distributing reservoir, which I have placed on the casemate in the gorge of the bastion. My reason for selecting this position will be given further on. The suction and forcing mains have been made 9 inches in diameter, to admit of an extension of the supply, if that should become necessary, and also because no pipes of intermediate size between 9 inches and 6 inches are procurable in Calcutta, and the latter, though just large enough for the 20 gallon per man supply, allows no margin for sediment, extensions, &c.

There are two pumps attached to the engine, which have plungers of 3 feet stroke and 6 inches diameter. With the engine working full power, these will make 30 double strokes per minute each, and discharge together about 35 cubic feet per minute. This is sufficient for the 20 gallon per man supply; but if a supply of 40 or 50 gallons per man is required from the tanks, either two additional pumps of the same size will be required, or, which would be better, two new pumps of 9 inches diameter and the same stroke substituted for the existing ones. The pumps were adapted for working in a well, and in order to use them in their new position, I have reversed the valves and cut short the connecting rod. I have reserved space for the duplicate engine in the building. The existing engine is 11-horse power, upright dome boiler, Chaplin's patent, which I expect will answer very well. But the other engine ought to be a horizontal one, as such will be easier to put into the vaulted building with reference to the position of the pumps. It should be high-pressure also, as it is not proper to have tall chimneys, which low-pressure engines require, in the out-works of the fort. It must be procured from England, and I do not therefore include it in this estimate. The probable cost of the engine, with pumps, boiler, &c., complete, will be about £500.

In the draft memorandum I proposed to distribute the tank water-supply for two levels, one high and the other low, but I have now abandoned the idea, chiefly because I found that the elevation of the low service reservoir in the ravelin as first proposed, was insufficient to deliver the water at the distances required. This necessitated the low-level being raised; and as the high-level reservoir on top of the Dalhousie barrack could also bear reduction, I found it advisable to amalgamate the two services into one, having a medium head of pressure. There were other considerations besides. Originally I proposed to make the distributing reservoirs of plate-iron, but I afterwards found these would be very expensive, and, being exposed to the sun, would make the water very hot and disagreeable to drink. If the reservoir could not be of iron it could not be put on the Dalhousie barrack. I could not raise the level of the low-service reservoir in the ravelin without destroying the command of fire from the enceinte, and I was thus driven to finding a new site for both reservoirs, and selected the casemate in the gorge of the King's Bastion.

I purpose to erect a brick reservoir 60 × 30 × 7 feet on top of this building, raised on arches so as to have its bottom on a level of 65 feet above datum. The following Table gives the levels of the different stories of the several buildings in the fort:—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Statement showing the levels of the different stories of barracks and other buildings in Fort William.

Names of buildings.	Level of ground floor.	Level of second floor.	Level of third floor.	Level of fourth floor.	Level of roof.
King's magazine store-room, ..	24·11	..	..	..	44·11
Day hospital, ...	23·76	..	..	..	..
Chowringhee gate quarter, ...	25·10	46·10	..	..	64·60
Queen's bastion, store-room floor,	25·17	..	..	..	43·17
Dalhousie barrack, ...	23·18	38·68	58·68	79·68	101·68
Staff barrack, ...	25·46	38·46	..	..	57·46
Main guard, ...	24·07	..	..	..	..
Queen's barrack, ...	29·40	49·40	69·40	..	89·40
North barrack, ...	23·90	38·90	..	..	58·90
Water-gate quarter, ...	25·06	47·06	..	..	65·31
South barrack, ...	23·67	37·92	..	..	58·23
Rampart barrack, ...	23·67	42·17	..	..	59·67
St. George's gate quarter, ...	25·74	46·49	..	..	66·49
Government house, ...	23·13	39·73	..	..	63·73
Treasury-gate quarter, ...	25·50	45·50	..	..	65·50
Conjee house, ...	24·69	..	..	..	..
Conductor Collin's quarters, ..	25·78	40·28	..	..	54·78
Royal barrack, ...	22·98	37·98	54·48	..	67·98

From this it will be seen that the reservoir will not be high enough to supply the top stories of the Queen's and Dalhousie barracks respectively, but will suffice for every other building, and will discharge even over the roofs of most of the two-storied buildings. The level of the reservoir, 65 above datum, was, in fact, fixed from the level of the third story of the Dalhousie barrack as follows:—

Height of third story above datum, ...	58·68
Head to drive through 900′ of 6″ main, ...	3·01
Ditto ditto ditto 35′ of 3″ ditto, ...	·25
Height of delivering cocks above floor of barrack, ..	3·00
Total, ...	64·94

The head required for the top story of the barrack, calculated in the same way, would have been 86 feet, which would have required the reservoir to be raised 50 feet above the casemate. To do this would have been very expensive and otherwise inexpedient, as giving an unnecessary pressure in all other parts of the fort. I therefore adopted the level of the third floor, and propose to erect a stand-pipe alongside of the reservoir, which can be thrown into operation by shutting off the reservoir from the forcing main, and allowing the water to pass direct into the distributing mains at a higher pressure, so as to fill cisterns on the top stories of the barracks above-mentioned. This will be found shown in the drawing. These high-level cisterns will be filled once a day or oftener if necessary, and the whole system of pipes will be under high pressure, while they are being filled. There is one advantage in this, that, in the case of fire or any other emergency, the water can be delivered at a higher pressure than usual at will.

From the distributing reservoir the 9-inch forcing main passes down the side of the casemate to the road, and then branches off into two 6-inch mains, as shown in the drawing. From these, 3-inch mains radiate at intervals into the out-works, except in the case of the cooly bazar gate, where I propose a 4-inch main to allow of an extension to the cooly bazar barracks hereafter. The 3-inch mains are larger than necessary, but they are the smallest cast-iron pipes to be had. Smaller pipes are made of wrought-iron tubes, and are much more expensive than the cast-iron ones. For instance, a 2-inch wrought-iron pipe costs nearly twice as much, length for length, as a 3-inch cast-iron pipe, and is not, of course, so useful as a main.

The house service will be effected by wrought-iron pipes 1-inch, and ¾-inch, according to the supply required. The men's barracks will be supplied with brass cocks one to each basin in the lavatories, and others at intervals of about 50 feet along each dining verandah. Officers' barracks will be supplied with one cock to each set of quarters, if practicable, in the back verandahs, but not when this brings them nearer together than 40 or 50 feet. Cook houses will be supplied from low stand-pipes placed outside the buildings on the road-side. I do not propose to do more than place one stand-pipe in each ravelin near the lamp posts, which will be sufficient for all purposes. But it is easy at any time to make extensions of the houses service where approved, as in the case of laying on gas. The positions of the stand-pipes are shown in the drawing.

I have procured all the necessary pipes from the Oriental Gas Company. They are ordinary socket pipes from ⅜ to ½-inch thick, which will be found to be amply strong enough, by reference to Table 14, Beardmore's Hydrology, page 59. I have not, however, been able to get any valves, and I shall submit an indent for such as I cannot make up myself, in order that they may be procured from England. The stand-pipes I am making up out of a lot of old cast-iron flange-pipes I procured from the arsenal.

By cutting them in half, plugging up the cut ends, and having an ornamental top cast with a flange, to screw on to the flanged end of the pipe, with a place for a brass cock, I hope to be able to turn out an economical and useful stand-pipe.

In conclusion, it may be considered necessary that I should show that the size of pipes and horse-power of engine are sufficient for the discharge *to be effected. In the first place* as regards the engine. The length of suction and forcing mains = 1,440 feet, having 10 bends of 90°, and discharging as a maximum the whole supply of 50 gallons per head for 5,000 souls in 10 hours, or 66·6 cubic feet per minute.

Then, loss of head from friction and bends, see pages 52 and 53, Beardmore's Hydrology, ...	=	8·46
And maximum lift from lowest level of tank to highest level of distributing reservoir, ...	=	60·
Total, ...	=	68·46

Then $\text{H. P.} = \frac{1}{\cdot 85} \times \frac{250{,}000 \times 10 \times 68{\cdot}46}{10 \times 60 \times 33{,}000} = 10{\cdot}16$, which is within the nominal power of the engine being erected. The latter is, therefore, capable of delivering the whole supply under pressure, if it should be decided to dispense with the aqueducts. At a certain time each day, the water will have to be forced to a level 21 feet higher than the distributing reservoir. The engine, under this extra head of pressure, will only be able to discharge at the rate of 14,800 gallons per hour, instead of 25,000 gallons; but this is still at the rate of nearly 30 gallons a head for 5,000 souls, and more than sufficient under the circumstances. The pumps have already been described above.

In fixing the size of the pipes, I have taken them respectively at 9, 6, 4, and 3 inches in diameter, as I have mentioned above, because such were the sizes procurable in the market nearest to the size I calculated to be necessary. The 9-inch main is capable of discharging the maximum supply likely to be required, when the water moves in it with a velocity of 150 to 180 feet per minute, and this is the highest velocity the steam-engine is likely to produce. The 6-inch main is in two branches, the longest of which is 2,400 feet. Assuming that each branch will be required to deliver an aggregate of 30 cubic feet per minute, at the rate of 1 cubic foot per 100 feet of its length, the following Table shows the progressive loss of head from friction, &c., at points 100 yards apart, calculated from Table 8, page 49, of Beardmore's Hydrology.

Distance from distributing reservoir, in feet.	Assumed discharges, gradually diminishing at the rate of 1 cubic foot per 100 feet of main.	Progressive loss of head.
0	30 cubic feet	0·
300	27 " "	1·2597
600	24 " "	2·2552
900	21 " "	3·0172
1,200	18 " "	3·5770
1,500	15 " "	3·9658
1,800	12 " "	4·2146
2,100	9 " "	4·3545
2,400	6 " "	4·4166

The longest branch, 3-inch main, is 710 feet. The loss of head due to this, assuming the required discharge at the end of the pipe to be 6 cubic feet per minute, is 4·7 feet. Therefore the total loss of head at the extreme point of the system of mains will be (4·416 + 4·7), say 9 feet. As the distributing reservoir is about 40 feet above the general ground-level of the fort, the water will thus be delivered at the farthest points of the fort with an available head of more than 30 feet, which is sufficient to throw over the tops of all single-storied buildings, and to supply the upper-stories of all other buildings, except the top ones of the Dalhousie and queen's barracks respectively. These, I have stated above, are to be supplied from small iron cisterns placed on them, and filled periodically when the water is placed under a higher pressure. If the main had been a 5-inch one instead of 6-inch, the loss of head would have been about 10 feet instead of 4·4, and the distributing reservoir would have had to be built 5 or 6 feet higher than I have proposed, in order to discharge into the same story of the Dalhousie barrack. The extra expense of this would, in the first place, have neutralized the saving in pipes, besides giving the disadvantage of a higher reservoir without its usefulness; and, in the next place, no 5-inch mains are procurable without sending to England for them. The size next larger than the 6-inch is the 9-inch main, which, on the other hand, is too large; I have thus, therefore, fixed on the 6-inch. The argument for the 3-inch is the same.

Abstract of Expense.

Separate estimates in detail are attached for each of the under-mentioned portions of the project, and a general abstract of the whole is given below. There is no detailed estimate, however, for erecting the steam-engine and pumps, for it was difficult to anticipate the quantity of work involved in it, and as it has been pushed on towards completion, I am enabled to include the actual cost in this general estimate, after allowing a margin for the final completion of the work.

		RS.
Estimate for	cast-iron under-ground mains, ...	20,236
"	wrought-iron service pipes,..	12,194
"	distributing reservoir, ...	10,836
"	filters, ...	6,387
"	erecting steam-engine and pumps, ...	3,500
	Total, ..	53,153

This is independent of the cost of the tank now under construction, Rs. 21,027, and of the further tanks, Rs. 1,50,000, which would be necessary for the purpose of storing the rain water required as per data assumed.

S. T.

[The Estimates have been passed, and the work is progressing.—Ed.]

No. XCV.

STRESSES ON LATTICE GIRDERS.

Notes on the Elementary Stresses in Girders of Lattice Bridges. BY J. HART, ESQ., C. E., *Executive Engineer, Dharwar.*

1. As the distribution of the loaded points in a girder will influence the intensity of the stresses in its various members; and also since the arrangement of these members must be known before the calculations of the stresses can be effected; the first step will be to prepare a diagram representing the elevation of the girder; and next to ascertain the probable loading per foot of span.

2. When this has been effected, the weight at each angle or "apex" of the latticing is readily obtained: at each apex, because the joists or transverse roadway beams, are usually placed only at these points so as to avoid shearing stresses on the horizontal members.

But whether such arrangement of the roadway beams be adhered to or not, is of no consequence, as we may, for all purposes of calculation, consider only the *resultant* of any other arrangement of loading, as the weight acting at the apices.

3. A weight at any apex is ultimately transmitted to the abutments, where the vertical stress produced by it will be inversely as its distance from either; that is to say, in a girder supported at both ends, the vertical pressure due to any weight on *one* abutment, will equal

$$\frac{\text{The weight} \times \text{the distance from the } other \text{ abutment}}{\text{Length of girder between abutments}}$$

Since horizontal members in framing do not transmit vertical forces *directly*, the stresses to produce this vertical pressure on the abutments must have passed through the diagonals of the latticing, and this they do in the manner following :—In diagram 1, Plate VII., which represents a lattice girder, let us consider the effect of a weight W_2 going towards the left support, L.

Its vertical pressure at L is $P_2 = \frac{W_2 \times d\,R}{L\,R}$, and it passes along diagonals *ab, bc, cd,* producing a pull in *cd,* and a compression in *ce* and *cb,* which act as struts.

The thrust along *cb,* produces also a pull in *bd* and *ab,* which latter gives a thrust in *ac,* and *a* L. If the line *dd′* be considered to represent in quantity and direction, P_2, the diagonals *cd, cb, ba,* will each represent the value of the stresses along them: call T_2 the stress on *cd*; then

$$T_2 : P_2 :: cd : dd',$$

whence if θ° be the angle the diagonals make with the vertical,

$$T_2 = P_2 \sec \theta^\circ$$

this, acting at the point *c,* produces a thrust in the horizontal direction, represented by *ce,* and in the diagonal by *cb.*

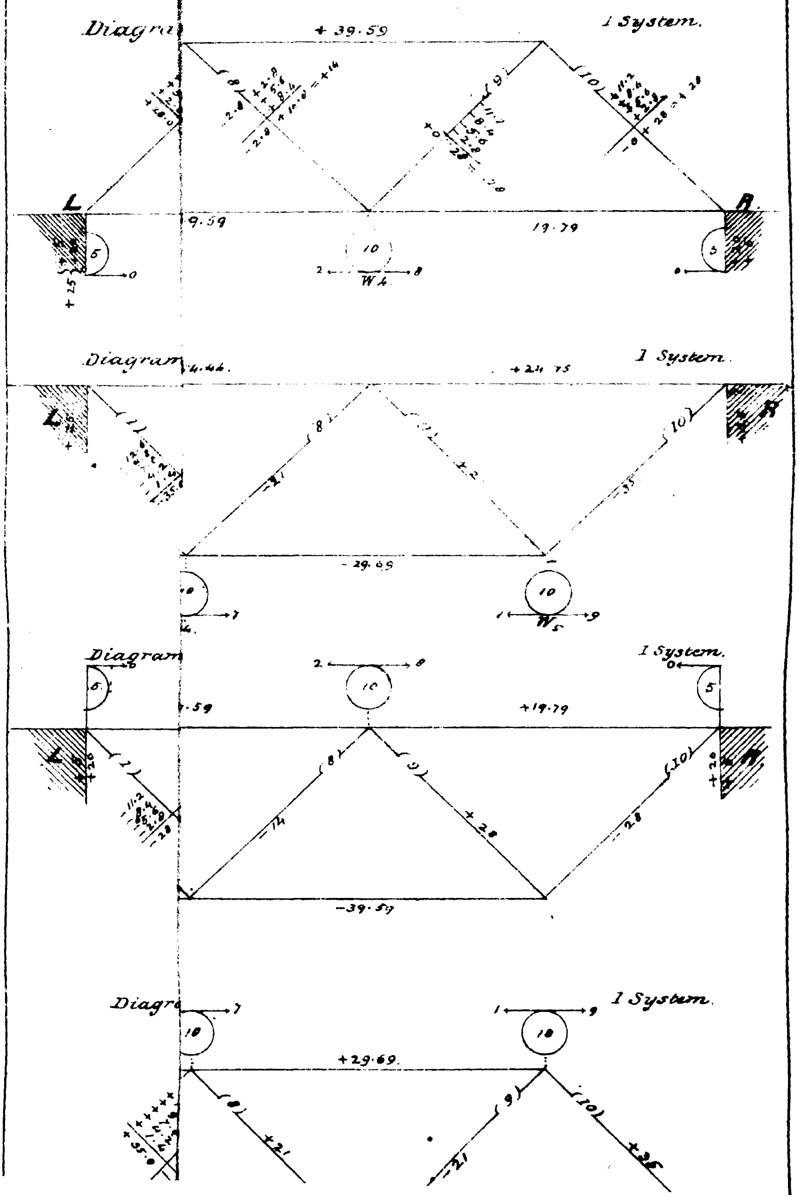
Whence it follows, that a $\left\{\begin{matrix}\text{tension}\\ \text{compression}\end{matrix}\right\}$ in any diagonal bar, produces an equal $\left\{\begin{matrix}\text{compression}\\ \text{tension}\end{matrix}\right\}$ in the bar meeting it, at the top or bottom chord.

4. If one weight only, W_2, rested on the beam, all bars from the point of its application to *one* support would be equally stressed, those towards the *other* would also be equally stressed, but the intensity of the stress on each side would be inversely proportional to the segments, into which the point of application of the weight divided the beam. If, however, another weight, W_1, were placed at *b,* the stress on *ab* would be increased by the effect $P_1 = \frac{W_1 \times b\,R}{L\,R}$, of W_1 towards L, multiplied by sec θ°.

In the above manner, by treating each weight separately, we get the sum of the stresses on each bar by a series of additions; the *algebraic* sum is here to be understood, because a compression and tension in the same bar necessarily produces a real stress equal only to the difference of the forces, and is called the *resulting* stress.

5. To illustrate the above method of ascertaining the stresses in a lattice girder, let us examine the diagram; it represents a beam of a *single* latticing, in which $\theta^\circ = 45^\circ$. The loading is supposed to be on the lower chord or boom.

P.


Diagra
1 System.
+ 39.59
19.79
W4
Diagram
1 System.
+ 24.75
- 29.69
W5
Diagram
1 System.
+ 19.79
- 39.59
Diagr
1 System.
+ 29.69.
+ 21
- 21
+ 35

Beginning with weight W_1, we see it produces a tension on bars 2 and 3, equal $\frac{W_1 \times bR}{LR} \sec \theta = \frac{10 \times 40}{50} \times 1{\cdot}4 = 11{\cdot}2$, and $\frac{W_1 \times bL}{LR} \sec \theta = \frac{10 \times 10}{50} \times 1{\cdot}4 = 2{\cdot}8$, respectively, and these stresses pass on towards the respective ends, producing alternate pulls or thrusts in the bars.*

If we proceed in like manner through all the weights, entering the stresses with their proper signs; that is (−) for a tension or pull, and (+) for compression or thrust, we obtain the total and resulting stresses, as shown in the diagram.

6. Since the resulting compression or tension in any bar is equal to the tension or compression in that which meets it at the top, it is therefore only necessary to calculate the stresses in all bars sloping one way, and put the same amount of compression or tension, each to each, on the bars meeting them at the top.

These bars, in which no increment of stress takes place when passing from one to the other, are called *pairs;* and when the load is on the lower chord, they meet each other at the top; but if the upper chord is loaded, they meet at the bottom.

7. Instead of entering the stresses on the diagonal lines in the diagram, they are sometimes tabulated thus:—

Weight.	Bars.									
	1	2	3	4	5	6	7	8	9	10
1	+ 11·2	− 11·2	− 2·8	+ 2·8	− 2·8	+ 2·8	− 2·8	+ 2·8	− 2·8	+ 2·8
2	+ 8·4	− 8·4	+ 8·4	− 8·4	− 5·6	+ 5·6	− 5·6	+ 5·6	− 5·6	+ 5·6
3	+ 5·6	− 5·6	+ 5·6	− 5·6	+ 5·6	− 5·6	− 8·4	+ 8·4	− 8·4	+ 8·4
4	+ 2·8	− 2·8	+ 2·8	− 2·8	+ 2·8	− 2·8	+ 2·8	− 2·8	− 11·2	+ 11·2
Resulting stresses,	+ 28	− 28	+ 14	− 14	± 0	∓ 0	− 14	+ 14	− 28	+ 28

This shows, according to para. 6, that when the weights are arranged along the bottom chord, since bars $\left\{\begin{matrix} 1 \text{ and } 2 \\ 3 \text{ ,, } 4 \\ 5 \text{ ,, } 6 \end{matrix}\right\}$ meet at top, and are *pairs,*

* It would have done equally well to have tabulated the effects P_1, P_2, and multiplied the result by sec $\theta°$, thus, for bar 1; $\left.\begin{matrix} +8 \\ +6 \\ +4 \\ +2 \end{matrix}\right\} = +20 \times 1{\cdot}4 = +28.$

if we calculate the tensions in bars 2, 4, 6, &c., we have the compressions in bars 1, 3, 5, &c., by simply changing the signs.

8. It is a general maxim in lattice girders uniformly loaded, that the resulting stresses in bars sloping *down* towards the centre are tensile; and in bars sloping *down* towards the ends, compressive.

9. Thus far we have neglected the effect of the horizontal components, *ce* and *bd*, of the forces mentioned in para. 3, and confined ourselves to the stresses on the bars.

The horizontal forces are those which stress the top and bottom chords producing always a compression in the former and a tension in the latter.

Referring to para. 5, we have found that the tension in the bar *cd*, due to the weight W_2, is $P_2 \sec \theta$; this, acting at *c*, is resolved in the directions *ce* and *cb*; the effects of the latter we have traced out in investigating the stresses on the bars, so that we are now concerned with the former only.

Its value is represented by the lines $ce = bd$, &c., but $ce = 2\ cd'$, and $cd' = cd \sin \theta$, therefore $ce = cd\ 2 \sin \theta = \frac{2\ cd}{\operatorname{cosec} \theta}$

10. In this manner, by tabulating the horizontal stresses due to each weight, we might get the sum of the stresses on top and bottom chords; but the method would be tedious and the mass of figures confusing. It will be better to take account of only the aggregate, or—as the case may be—resulting bar-stresses, which, multiplied by twice the sine of the angle of latticing, will give the + or − stresses, on the top or bottom chords, due to that bar, towards the centre; that is, stress on $\left\{\begin{matrix}\text{top}\\ \text{bottom}\end{matrix}\right\} =$ $\left\{\begin{matrix}\text{T} - \text{C (for tension bars)}\\ \text{C} - \text{T (for compression bars)}\end{matrix}\right\} 2 \sin \theta.$

This being done for each bar, gives a series of horizontal stresses, increasing from the centre towards the ends. For example, in the diagram, the compression, along the top chord due to bar 2, is

$$28 \times 2 \sin \theta, \text{ from } a \text{ to centre,}$$

and to bar 4, is

$$14 \times 2 \sin \theta, \text{ from } c \text{ to centre, and so on.}$$

Of course the *total* stress from *c* to centre will be the sum of these $= 42 \times 2 \sin \theta$, and since $\theta = 45°$, the total stress of compression at the centre of the top chord is $42 \times 1{\cdot}4 = 58{\cdot}8$

Therefore, *the stress at any point in the* $\left\{\begin{matrix}\text{top}\\ \text{bottom}\end{matrix}\right\}$ *chords will equal* *the sines of the resulting stresses on all bars, sloping down* $\left\{\begin{matrix}\text{to}\\ \text{from}\end{matrix}\right\}$ *the centre, which touch the* $\left\{\begin{matrix}\text{top}\\ \text{bottom}\end{matrix}\right\}$ *chord between the point and the end of the girder, multiplied by* 2 sin θ; and this stress is a maximum when the whole beam is loaded.

11. It would follow from the above, were it not otherwise evident, that the *bottom* chord is *always* in *tension*, and the *top always* in *compression*.

12. The method by which the stresses have been arrived at in the foregoing paragraphs for a beam of a single system, is equally applicable to one of any number of systems; because each system of the bracing may be considered to be totally independent of the others, the effect of the rivetting at the crossings producing, in the first instants of flexure, no practical disturbance in the stresses.

The useful effect of the rivetting in stiffening the compression bars will be noticed hereafter.

13. A *system* may be defined to be the series of diagonal lines meeting each to each at the top and bottom chords, and so running in a continuous zig-zag throughout the girder.

When one such zig-zag is crossed by another, the latticing is of *two* systems; by two others, of *three* systems; and so on.

The number of systems of latticing in any girder, is readily found by adding one to the number of times any whole diagonal line or bar is crossed by others; or, by doubling the number of diagonal spaces, or lozenges, in the depth of the beam.

Girders of one system are sometimes termed *triangular* girders, while those of more than one are called *lattice;* but there does not appear to be any good ground for the distinction, as the former is evidently rudimentary of the latter.

14. The load on girders being for the present supposed to be uniformly distributed, it follows that the weights at the apices will be of less intensity in proportion to the number of systems; and so will of course the stresses on the bars: for example, in a beam of given span and depth, and with a given uniform load, the weight at each apex in a single system, will be double those in a similar beam of two systems.

This may be seen by comparing the examples of beams shown by diagrams 2 and 6.

15. The diagrams in Plate VIII., represent a series of similar lattice

girders, with the different arrangements of loading and bracing that usually occur. The stresses are calculated and placed on the diagrams, in order to afford a comparison of the value of the several arrangements.

The load is supposed to be one ton per foot of span, and of course the stresses are those due to the unit of load, and so may be considered as co-efficients of the load.

The span is supposed be 50 feet.

The numbers in the circles represent the weights, which may be assumed to act at each apex; those on either side of the circles are the proportions of these weights, which, according to the principle of the lever, go in the direction of the respective points of support; that is, they are the effects P_1, P_2, &c., of the weights W_1, W_2, &c.

The stresses are obtained by adding together the several effects of the different weights, and this has been so done, chiefly for the purpose of testing and illustrating the accuracy of the formula given further on.

In the examples 2, 4, 7 and 8, which are examples of unsymmetrical bracing, the results are not *strictly* accurate, because the last weights on the beams could not in reality be so great as shown; for the reason that each weight at the apices being considered to be the resultant of an uniformly distributed load, a *full* bay of the latticing should exist between the last apex and the abutment to produce the *full* loading: for example, in diagram 2, the last weight instead of being 10, should have been $\frac{10+5}{2}$ $= 7{\cdot}5$ instead of 10; this is, however, a matter of no practical importance, and such girders are seldom, and ought never to be, constructed.

Sec θ = sec 45°, is taken at 1·4 for simplicity; this not being strictly accurate, the stresses shown are therefore somewhat less than the truth.* In diagrams 2, 4, 8 and 9, the loaded chord is not shown con-

* It would have simplified the calculations, although not have explained the principle so clearly, had the vertical effects P_1, P_2, only of the weights W_1, W_2, been taken, and the results only, multiplied by sec $\theta°$: for example, in case of bar 2, diagram 1.

$$P_1 = -8$$
$$P_2 = -6$$
$$P_3 = -4$$
$$P_4 = -2$$

$$\left.\begin{matrix}\text{resulting}\\ \text{stress}\end{matrix}\right\} -20 \times \sec\theta = -28, \text{ or more correctly } -28{\cdot}28$$

and when the bar stresses came to be transferred it would have been $\frac{20 \times \sec\theta}{\cos\theta} = \frac{20 \times 1{\cdot}414 \times 2}{1{\cdot}414} = 20 \times 2 = 40$; or double the bar effects in the case of 45° latticing.

nected with the abutments, but of course in practice this would have been the case, such would however make no alteration in the stresses. In the calculations of 7, 8 and 9, only approximate decimals are used. In diagram 1, the calculations are given in detail for the whole beam; in the others, details are only given for one-half, and the resulting stresses entered on the other.

In diagrams 8 and 9, the calculations owing to want of room in the drawing are tabulated (*see* Table, pages 45 and 46) and the results only entered. The systems are shown of different colored lines, to guide the eye. Diagram 5 represents a common case of Warren's girder, in which all the points are loaded; in this case there is no change of stress, whether the upper or lower chord is loaded, the only difference being that in the former case the verticals, *a* W_2, are in compression, and in the latter, in tension. These verticals merely serve to transmit the weights to the apices.

16. The method of successive additions is a laborious mode of arriving at the stresses in the bars, and the following formula will be found to shorten the calculations:—

W_1, the weight at each apex.

w, the fixed load per foot of span.

w', the rolling load per foot of span.

S, the span in feet.

θ°, the angle which the bar makes with the vertical; the secant of this angle is sometimes expressed as the ratio of the length of bar to depth of beam.

L, the distance of the $\left\{\begin{matrix}\text{foot}\\ \text{head}\end{matrix}\right\}$ according as the loading is on $\left\{\begin{matrix}\text{bottom}\\ \text{top}\end{matrix}\right\}$ of the bar whose stresses is examined, measured to the support from which it slopes $\left\{\begin{matrix}\text{up}\\ \text{down}\end{matrix}\right\}$.

l, the distance, to same end as in above, of the last weight, acting on the system of triangles in which the bar is.

N, the number of weights acting on the system of which the bar forms part, in the space L, inclusive of the weight at the point of attachment of the bar to the loaded chord.

In those bars which cut the vertical over the points of support, it would have been equal to the bar effects: for example, for stresses from bar *a* L on bottom chord, the tension would be — 20 exactly.

T, the *maximum* tension;

C, the *maximum* compression;

that is to say; the greatest − and + stress that could come on with *any* arrangement of the loading; for in the case of *uniform* l there might be a considerable stress of the opposite character, which be deducted if the resulting stresses were sought; this will be bet derstood when the effect of the rolling or passing, and fixed or load, is being considered.

When we examine the process of arriving at the sum of the s (para. 5), we see that the weights acting at the apices of the triang are each resolved into two sums bearing to each other the inverse r their respective distances from the points of support, and since it necessary (para. 6) to take account of the sums towards one side, th tion $\frac{WL}{S}$ represents the vertical effect passing towards *one* side weight, W, placed at a distance L from the *other*; and its effect direction of the diagonal braces, through which it must pass, is $\frac{W}{S}$

If we examine the stresses in any bar of diagram, No. 1: second bar, *ab*, we have the stresses on it by the weights,

$$W_1 = \frac{WL_1}{S} \sec\theta$$
$$W_2 = \frac{WL_2}{S} \sec\theta$$
$$W_3 = \frac{WL_3}{S} \sec\theta$$
$$W_4 = \frac{WL_4}{S} \sec\theta$$

an arithmetical series which may be written thus: $\frac{W}{S} \sec\theta\,(L_1$ &c., $L_4)$; the number of terms in it is of course the number o towards one side, which act on the bar through the several " the system in which it is. The beam taken as an example bein single system, the number of weights is *all* the weights on the tween the bar and the end; but had the beam been of two sy number acting on the bar would have consisted of every secon if of three systems, every third weight, and so on. The last ... f the last weight from the end, *l*, in the notation.

The sum of the series is therefore in general terms—

$$\frac{W \sec \theta}{S\ 2} N (L + l) = T \text{ or } C \ldots\ldots (1)$$

17. When it is desirable to have a formula expressed in terms of bays or lozenges of the latticing, such as xy in the diagram; the series becomes—

$\frac{W}{n} \sec \theta \left\{ \Sigma (N - 1) + x + \Sigma (N - 2) + x + \&c., \right\} x$, and the number of terms equal $\frac{N}{2}$; wherefore $\frac{W}{N} \frac{N}{2} \sec \theta \left\{ \Sigma (N - 1) + 2x \right\}$ is the series, when—

n, is the number of lozenges or bays in span.

x, the number of bays, from last weight acting on the system in which the bar is, to the end of the beam.

Σ, the number of systems in girder.

If d be the number of bays in the depth of the beam then, $\Sigma = 2d$ (para. 13), and—

$$\frac{W \sec \theta}{n} N \left\{ d (N - 1) + x \right\} = T \text{ or } C \ldots\ldots (1a)$$

which gives the same results as equation 1.

18. The following is the application of these formula to bar 4, of diagram 1—

By formula 1, $T = \frac{10 \times 1{\cdot}4 \times 3}{2 \times 50} (30 + 10) = {\cdot}42 \times 40 = 16{\cdot}8$

By formula 1a, $T = \frac{10 \times 1{\cdot}4 \times 3}{5} \left\{ {\cdot}5 (3 - 1) + 1 \right\} = \frac{84}{5} = 16{\cdot}8$

To bar 5, of diagram 6.

By formula 1, $T = \frac{5 \times 1{\cdot}4 \times 4}{2 \times 50} (35 + 5) = {\cdot}14 \times 80 = 11{\cdot}2$

To bar 11, of diagram 8.

By formula 1, $C = \frac{3{\cdot}33 \times 1{\cdot}4 \times 2}{2 \times 50} (15 + 5) = {\cdot}466 \times 40 = 1{\cdot}86$

To bar 5, of diagram 5.

$$C = \frac{5 \times 1{\cdot}4 \times 5}{2 \times 50} (25 + 5) = {\cdot}35 \times 30 = 10{\cdot}5$$

19. The test of the accuracy of the calculation by series of additions of stresses in the bars, is to resolve vertically downwards the stresses on all those bars which cut the verticals over the points of support, and their sum should equal the total heights on the beam; this of course is useless as a test when we use the formula, but it would prove the accuracy of its application to the end bars.

20. For the stresses on the top and bottom chords, we find

if H_c = the horizontal stresses on the top chord at any point x

and H_t = " " bottom "

then $\left.\begin{matrix} H_c \\ H_t \end{matrix}\right\}$ = sum of all *resulting* $\left\{\begin{matrix} \mp \end{matrix}\right\}$ stresses in the bars from end of beam to x, multiplied by $2 \sin\theta = 2 \sin \left\{\begin{matrix} T_r \\ C_r \end{matrix}\right\} \sin\theta$.

---

21. When a girder is weighted with a *permanent* and *uniformly distributed* load, the *resulting* stress, that is, the algebraic sum of the stresses due to the distributed weights, is the greatest for which we have to provide. But, when there is a considerable *travelling* load in addition, the weighting *may* be partial and uneven; in such case the greatest *bar* stress will be the "resulting" stress due to the permanent load, plus the maximum due to that passing.

That is to say, for a permanent or bridge load, the greatest stress

$$M_b = \left\{\begin{matrix} T_b - T'_b \\ C_b - C'_b \end{matrix}\right\} = \left\{\begin{matrix} T_b - c_b \\ C_b - c_b \end{matrix}\right\} = R_b \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and for a combined bridge and passing load, the greatest stress

$$M_{bp} = \left\{\begin{matrix} T_{bp} - T'_{bp} + T_p \\ C_{bp} - C'_{bp} + C_p \end{matrix}\right\} = \left\{\begin{matrix} T_{bp} - c_{bp} + T_{bp} \\ C \quad - t_{bp} + C_{bp} \end{matrix}\right\} \ldots\ldots\ldots\ldots \quad (3)$$

the *upper* of the bracketted notations being used when the load is placed on the top chord, the *lower* when on the bottom chord.

$\left\{\begin{matrix} T \\ C \end{matrix}\right\}$ is the maximum stress due to the loading on $\left\{\begin{matrix} \text{top} \\ \text{bottom} \end{matrix}\right\}$ obtained for the bar examined by formula 1, 1a, $\left\{\begin{matrix} c \\ t \end{matrix}\right\}$ that obtained by transfer from the other bar of the "pair" = $\left\{\begin{matrix} T' \\ C' \end{matrix}\right\}$ that obtained by the same formula for the other bar of the "pair;" that is, the bar meeting the bar examined at the unloaded chord.

The letters $_b$, $_p$, are merely *deponents* showing the portions of the loading used in obtaining the several strains; just as we write—

W_b = the bridge or permanent load at each apex.

W_p = the passing or travelling load at each apex.

M_b occurs in any bar when the whole load is on M_{bp}, when the passing load, extending from the end of the girder from which the bar examined slopes *away*, reaches to the point of attachment of the bar to the chord.

DIAGRAM 9.

S.

	13	14	15	16	17	18	19	20	21	23
	*	*	*	*	*	*	*	*	*	*
18	− ·35	+ ·35	− ·53	+ ·53	− ·70	+ ·70	− 0·18	+ ·18	− ·35	− ·53
88	+ 2·45	+ 1·05	+ 2·28	+ 1·23	+ 2·10	+ 1·40	− ·88	+ ·88	− 1·05	− 1·23
93	+ 1·75	− 1·75	+ 1·58	− 1·58	+ 1·4	− 1·4	+ 1·93	+ 1·58	+ 1·75	+ 1·58
23	+ 1·05	− 1·05	+ ·88	− ·88	+ ·70	− ·70	+ 1·23	− 1·23	+ 1·05	+ ·88
53	+ ·35	− ·35	+ ·18	− ·18			+ ·53	− ·53	+ ·35	+ ·18
39	·35	3·15	·53	2·64	1·40	2·10	1·06	1·76	1·40	1·76
06	·60	1·40	4·92	1·76	3·50	2·10	3·69	2·64	3·15	2·64
33	+ 5·25	− 1·75	+ 4·39	− ·88	+ 2·10	− 0·0	+ 2·63	+ ·88	+ 1·75	+ ·88

BOTTOM BAYS.

a′.	*b′.*	*c′.*	*d′.*	*e′.*	*f′.*	*g′.*	*h′.*	*i′.*	*j′.*
− ‡6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82
− ‡6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19
	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17
		− 9·90	− 9·90	− 9·90	− 9·90	− 9·90	− 9·90	− 9·90	− 9·90
			− 8·68	− 8·68	− 8·68	− 8·68	− 8·68	− 8·68	− 8·68
				− 7·42	− 7·42	− 7·42	− 7·42	− 7·42	− 7·42
					− 6·21	− 6·21	− 6·21	− 6·21	− 6·21
						− 2·97	− 2·97	− 2·97	− 2·97
							− 3·72	− 3·72	− 3·72
								− 2·47	− 2·47
									− 1·24
− 13·01	− 24·18	− 34·08	− 42·76	− 50·18	− 56·39	− 59·36	− 63·08	− 65·55	− 66·79

22. In either case of loading the stresses in the *top* and *bottom* chords are greatest when the full load is on; that is, when the passing load extends over the *whole* span.

23. When the ratio of the intensities of the two loads—bridge and passing—to each other is known, formula (3) becomes

$$M_{bp} = \left\{ \begin{matrix} T_b - T'_b + q\,T_b \\ C_b - C'_b + q\;C \end{matrix} \right\} = \left\{ \begin{matrix} (1+q)\,T_b - T'_b \\ (1+q)\,C_b - C'_b \end{matrix} \right\} \quad \ldots\ldots\ldots \quad (4)$$

$\frac{1}{q}$, being the fraction that the bridge is of the passing load—or; since it is more convenient, for calculating the stresses, to obtain at once the maximum stresses due to the combined loads, the formula may be put thus—

$$M_{bp} = \left\{ \begin{matrix} T_{bp} - \frac{1}{q} T'_{bp} \\ C_{bp} - \frac{1}{q} C'_{bp} \end{matrix} \right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

and hence—

$H_{bp} = 2\ R_{bp} \sin\theta =$ the greatest stress on top and bottom chords due to M_{bp}.

R_{bp}, being the resulting bar stress due to the whole bridge and passing load, supposed to be uniformly distributed.

24. When we come to apply these formula to practical design, one of the first questions which present themselves is the probable amounts of the loads W_b, W_p.

It is a difficult matter to say beforehand accurately what will be their respective values, as much depends on the form of structure adopted, but they may be approximated to, as follows:—

The bridge load will consist of:—

1. The girder weight for ordinary spans, usually between 50 to 500 lbs. per running foot.
2. The platform weight, for ordinary spans, usually between 20 to 30 lbs. do.
3. The metalling or ballast depending on depth used, 100 to 120 do.
4. A body of men, such as a crowd, 70 to 80 do.

The last is in reality a passing load; but one which, when the third item is provided for, it is not necessary to consider apart from the bridge load.

25. An equation for the intensity per foot of span of the bridge load will therefore have values between—

$w_b = 50 + 190\,b$, and $w_b = 500 + 230\,b$; in which
b = the breadth of platform to be supported by girder.

26. In railway bridges the passing load is usually assumed to be 1 ton per foot run per line of rails, and this is probably as much as it can possibly be; the stress of this load will depend on the position of the girders; and consequently, on the design, so that, each case must be treated on its own merits.

27. Indeed, in the case of any bridge it will be well to make a rough design of the girder before making final calculations as to the strength of its component parts; and then, assuming outside values for the loading, calculate the weights on the girder, and the quantities of the girder itself; from which the weight of the structure may be closely approximated to.

28. The *depth* of Lattice girders varies in practice from $\frac{1}{10}$ S, in small to $\frac{1}{16}$ S in large spans. This depth may be considered as being the depth from angle to angle of the axial lines of the bars where they touch the chords; in which case, it would be called the effective depth.

The following outside values for $\frac{D}{S}$ will be found suitable:—

For spans of 40 feet and under, ...	$\frac{1}{10}$
„ over 40 feet and up to 100 feet, ...	$\frac{1}{12}$
„ „ 100 „ „ „ 150 „	$\frac{1}{14}$
„ „ 150 „ „ over, ...	$\frac{1}{16}$

but they will somewhat depend also on the loads to be carried.

29. The *angle* of *latticing*, $\theta°$, varies from 30° to 45°; the former is that adopted in Warren's triangular girders: but it can be proved on theoretical grounds, and is shown by practical experiment, that the latter is the more economical of the two.

On this angle depends in a measure the number of *systems*, for the smaller the angle the shorter will be the bays of the latticing; and since the lengths of the bays regulate the distances of the transverse roadway girders from each other, it is evident that the smaller the angle the less *may* be the numbers of systems.

It is assumed in the above that, to avoid cross strains on the material of the chords, the transverse girders, which carry the load of the road-ders; and, consequently, λ, the distance apart of the roadway girders = the length of opening of the "bays."

If therefore we obtain the maximum value for λ, *we may proceed to determine the limiting number of systems* Σ, *for a girder of any given span and depth.*

30. The bearing which can be given to the planks composing the platform is often the practical limit to the distance apart of the roadway girders; this can seldom exceed 8 feet; hence, if we make—

$\frac{1}{m}$ = the ratio of the depth of beam to its span $= \frac{D}{S}$; and

d = number of diagonal spans in depth of beam $= \frac{D}{\lambda}$,

we have $d = \frac{S}{m\lambda}$ and since $\Sigma = 2\,d$,

$$\text{therefore } \Sigma = \frac{2\,S}{m\,\lambda} \quad \ldots\ldots\ldots\ldots \quad (6)$$

from which equation, provided we assume the values of $\frac{D}{S}$ to be those given in the 28th para., we deduce that—

A single system *may* be used *up to* spans of,			...	...	40
Two	do.	do.,	...	...	110
Three	do.	do.,	...	...	160
Four	do.	do.,	...	...	250

and so on.*

It will be found advisable that in design, $\frac{S}{\Sigma}$ be a *whole* number.

31. The difficulty of long bays, is sometimes got over in single systems, such as Warren's girders, by transferring the weights to the apices of the unloaded chords by either vertical struts or suspension bars, as shown in diagram 5; but this arrangement is of doubtful economic utility, and there still remains the objectionable length of unsupported strut in the case of the compression bars.

In lattice girders—girders of more systems than one—the crossings of the tension bars, which are rivetted to those in compression, tend to assist in retaining the struts in the line of stress, and subdivide what would otherwise be long pillars into a series of shorter ones. This consideration serves to explain the apparently anomalous rigidity of lattice girders formed only of thin bars.

* These are extreme limits, and for the large spans, the unsupported struts will probably be found to be too long, and the strains on single bars very great.

32. To more clearly illustrate the practical application of what has been written we proceed to design a lattice girder, suitable for a bridge to carry a public road of 22 feet in width over a span of 100 feet. Assuming in the first instance, that the design will consist of two main longitudinal girders, carrying between them a roadway of planks and metalling supported on timber roadway beams, which are placed, one at each apex of the latticing of the main girders.

$$\text{Let } D = \frac{S}{14} = 7{\cdot}143, \quad \Sigma = 2, \quad \theta^\circ = 45^\circ$$

from these data we proceed to prepare a diagram as mentioned in the 1st para.

Let as also assume, in order to exemplify the mode of treating the *passing* load, that a crowd of people moves along the bridge.

w_b will probably be $300 + 130\,b = 300 + (130 \times 11) = 1730$ lbs.

w_p „ $80\,b = 80 \times 11 = 880$ lbs.

If, therefore, we use formula $1a$ in this instance—because $7{\cdot}143$ is not a convenient number to work with—we have the following data—

$$W_b = w_b\,\lambda = 1730 \times 7{\cdot}143 = 12357{\cdot}4 \text{ lbs.}$$

$$W_p = w_p\,\lambda = 880 \times 7{\cdot}143 = 6285{\cdot}8 \text{ lbs.};$$ or, since it is more convenient to have the result in tons, we have—

$$W_b = \frac{12357{\cdot}4}{2240} = 5{\cdot}51 \text{ tons.}$$

$$W_p = \frac{6285{\cdot}8}{2240} = 2{\cdot}8 \text{ tons; and therefore } W_{bp} = 8{\cdot}31 \text{ tons.}$$

$n = 14$, $d = 1$, $\sec\theta = 1{\cdot}414$ and $\frac{1}{q} = \frac{1}{2}$ nearly. And since $\frac{W_{bp}}{n}\sec\theta = \frac{8{\cdot}31}{14} \times 1{\cdot}414 = {\cdot}83931$, or ${\cdot}84$ very nearly.

Formula $1a$ becomes ${\cdot}84\,N\,(N - 1 + x)$.

Thence we obtain the maximum stresses on each bar, which would be caused by a series of weights, W_{bp}, on the girder; as shown in columns 6–7 of the annexed Table.

If from each of these total stresses we deduct $\frac{1}{q} = \frac{1}{2}$ part of itself, columns 8–9, we obtain the differences, columns 10–11, which are the greatest stresses which are to be provided for in the bars, according to formula 5.

Again, the differences of the maximum bar stresses, $T_{bp} - T'_{bp} = T_{bp} - c_{bp}$, multiplied by $2 \sin 45^\circ = 1{\cdot}414$, gives the stresses on the chords due to the total loading, as shown in columns 14–15; and the sum of

girder, gives the stress on the bay in question, as shown in columns 16 and 17.

In calculating this Table by the formula we see that, if we consider those bars only which slope one way, as soon as we find the two or three first bar stresses we can easily, without further reference to the diagram, write the series N (N − 1 + x). N is increased by 1 at every second bar, and x is 1 and 2 at each alternate odd numbered bar. If we now reverse the proceeding and begin at the right side of the beam, we obtain the stresses for all bars sloping the reverse way; that is to say, in the case before us, the tensions on bar 28 is the same as that on bar 1

26	„	„	3
24	„	„	5
&c.,	&c.,		&c.,

and we write these tensions in the table.

c_{bp}, the compression in any bar is equal to the tension T'_{bp} in the bar which meets it at top; and therefore, since the bars are numbered consecutively, the compression on a bar sloping down to the $\left\{ \begin{matrix} \text{right} \\ \text{left} \end{matrix} \right\}$ is the tension on the bar next $\left\{ \begin{matrix} \text{less} \\ \text{greater} \end{matrix} \right\}$ in number; that is—

c_{bp} in bar 3 = T_{bp} on bar 2
„ 4 = „ „ 5
„ 5 = „ „ 4, and so on.

It is to remembered that T is the stress got for the bar by the formula, $c = T'$, that got by transfer of the tension on other bars of the "pair."

33. We have now in this Table the stresses on all the chief parts of the girder, and it remains only to determine the scantlings of the iron by which these stresses are to be resisted.

Authorities differ considerably as to the *working strains* suitable for structures of wrought-iron.

The working strains $= f' = \dfrac{\text{ultimate resistance of the material}}{\text{factor of safety}}$ depends chiefly on the value of this factor.

Rankine makes it for iron = 6 for rolling loads and rivetted structures,* and if we call the ultimate resistance or modulus of rupture of the material f; therefore $f' = \dfrac{f}{6}$; but since the modulus of rupture is not alike in wrought-iron for both tension and compression, we make—

* For steady loads, he makes it 3; that is, he makes the factor of safety for rolling loads double that for permanent loads.

f_t, the modulus for tension.

f_c, „ „ compression.

f'_t, the working stress for tension.

f'_c, „ „ compression.

Rankine makes, $f_t = 60{,}000$ lbs. $f'_t = 10{,}000$, or 4½ tons nearly,

$f_c = 36{,}000$ lbs. $f'_c = 6{,}000$, or 2¾ do., do.,

while Fairbairn mentions 6 tons per square inch as a safe working strain.

On the other hand, the Board of Trade limits it to 5 tons per square inch.

Others, by making allowance for rivet holes, deduce $f'_t = f'_c = 4\frac{1}{2}$ tons.

If, however, we assume as safe guides the values taken by Mr. Barton, for the Boyne Viaduct, the largest I believe yet constructed, we will have $f'_t = 5$ tons and $f'_c = 4\frac{1}{2}$ tons, and to obtain the areas of our material in square inches, we have $A = \frac{-\text{stresses}}{f'_t}$ for material in tension, and $\frac{+\text{stresses}}{f'_c}$ for compression.

34. We now make an abstract of the table of stresses in the subjoined form, and obtain the *areas* of our iron, as shown in column 5.

The distribution of the material—that is, the scantling and arrangement of the members of the girder, present some difficulty, and involve principles, a discussion of which, although exceedingly interesting, would be out of place in the present notes.

The attached table of areas page ~~352~~ 21, will assist in the determination of the scantlings to be entered in the 6th column of the abstract.

ABSTRACT OF TABLE OF STRESSES IN EXAMPLE GIRDER.

Members of girders.	Numbers on the diagram.	Greatest stresses in tons.	f_t.	Areas, square inches.	Scantlings, inches.	Remarks.
TENSION BARS. Those sloping down and towards centre.	1	41·16	5	8·23	2 bars 6¾ × ⅝	
	3	35·28	„	7·06	„ 5¾ × ⅝	
	5	29·82	„	5·96	„ 4¾ × ⅝	
	7	24·36	„	4·87	„ 4 × ⅝	
	9	19·32	„	3·86	„ 3¼ × ⅝	
	11	14·28	„	2·86	„ 2¾ × ⅝	
	13	9·66	„	1·93	„ 2 × ½	Packing pieces ⅛ inch thick will be required here.

Members of girder.	Numbers on the diagram.	Greatest stresses in tons.	f_t	Areas, square inches.	Scantlings, inches.	Remarks.
Bottom Chord.	VIII	49·88	,,	9·98	Plates* 24 × ¼	† This plate is a little stronger than necessary, as it has to resist a shearing stress due to half the weight of beam.
	IX	91·45	,,	18·29	† In addition to 4 L irons, 4 × 3 × ½ running along chord. ,, 24 × ½	
	X	124·71	,,	24·94	,, 24 × ¾	
	XI	149·65	,,	29·93	,, 24 × 1	
	XII	166·27	,,	33·25	,, 24 × 1¼	
	XIII, XIV	174·58	,,	34·92	,, 24† × 1¼	
Compression Bars. Those sloping down and away from centre.			f_c			In these three bars (2, 4, 6) we make very little allowance for the resistance of the inner flanges of the L irons, but which of course take much of the strain.
	2	35·28	4·5	7·84	2 L irons 6 × 4 × ⅝	With cross latticing.
	4	29·82	,,	6·62	,, 5 × 4 × ⅝	Do.
	6	24·36	,,	5·41	,, 4 × 3 × ⅝	Do.
	8	19·32	,,	4·29	2 bars 3½ × ⅝	This might perhaps better have been an L iron 3 × 2 × ⅝.
	10	14·28	,,	3·17	,, 2¾ × ⅝	
	12	9·66	,,	2·14	,, 2 × ⅝	
	14	5·04	,,	1·12	,, 2 × ½	Packing pieces will be required here.
Top Chord.	I	58·20	f_c 4·5	12·93	† In addition to 4 L irons 4 × 3 × ½ running along chord. Plates† 24 × ¼	† Of these 4 L irons we only include the top flanges = 6 square inches, in the area to resist the horizontal stresses in the chords, the vertical flanges go as stiffening and for excess of strength.
	II	108·08	,,	24·01	,, 24 × ¾	
	III	149·65	,,	33·25	,, 24 × 1⅛	
	IV	182·91	,,	40·64	,, 24 × 1½	
	V	207·85	,,	46·18	,, 24 × 1⅞	
	VI	224·47	,,	49·88	,, 24 × 1⅞	
	VII	232·78	,,	51·72	,, 24 × 1⅞	

* These plates should be in a series of layers breaking joint, as in a built beam, as they are in tension.

† These plates may be in any convenient thicknesses abutting against each other, as they are in compression.

35. A further point to be settled regarding our design, before we proceed with the determination of the scantlings, is whether we are to adopt the form of a "box" lattice, or that of a single "web."

It will be readily admitted that the box form is superior in stability and stiffness to the web; but we also find that a box is forced on us by the scantlings required. Our maximum bar area is to be 8·23 square inches; this would, if the single web form be adopted, require a bar 13½ inches wide, which would be contrary to all precedent; again, the maximum area of chord, at the centre, would require plates over 3 inches deep, and 17 inches broad, which would be impracticable; or over 6 inches deep, and 8 inches wide, which would be a weak construction.

We therefore select the "box" form for our design; and make it 1 foot 6 inches from out to out of the plane of the bars.

By adopting a "box" girder we lose in requiring an extra width of pier and abutment; but we gain in lateral stability, and are enabled to stiffen our compression bars by a transverse bracing; we also so keep the centre of gravity of the material of the booms nearer the line of stress imposed by the diagonal bracing of the girder.

36. It is also well, as far as possible, to maintain an uniform thickness of bar, so that there may be no necessity for packing pieces between the angle irons, which connect the bars with the plates of the chords; these pieces tend to lengthen the rivets, and so weaken them, and merely add useless weight to the structure.

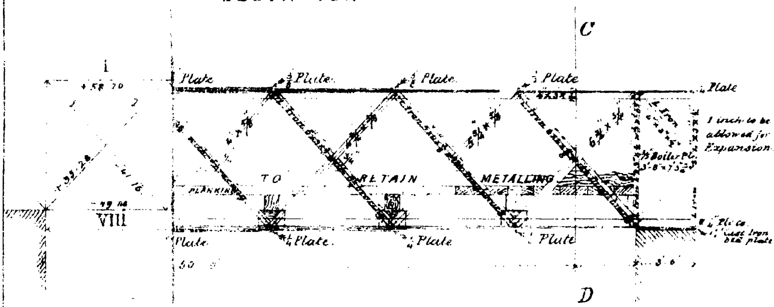
Great nicety in adjusting areas to stresses is not necessary in practice, as it is found that great varieties of scantling are inconvenient.

37. We can now draw the girder, as in Plate by forming its several members over the skeleton lines of the diagram.

38. Our girder, as now drawn, is in reality only a *provisional* beam; inasmuch as it is designed on assumed data, which can only approximate the truth; if we seek greater accuracy, the next step will be to calculate its weight, and that of the roadway platform as designed; and then, if the discrepancies between this weight and that which we have assumed, are considerable, we must recast our design, substituting in our calculations the new data for that assumed. In our example, the *assumed* bridge load was $300 + 130\,b$, which included as variables :—

The girder weight $= 300$ lbs. per foot run, and

ELEVATION.



Note.– The thickness of Planking

ess of Planking designed is such that its Maximum deflexion will not

r ft run.–

We shall see now how much our provisional beam proves it to be.

We find by the drawing that from the abutments to the middle, 50 feet, it contains—

r. ft.		in.	in.	lbs.	lbs.
92·8	Plates in top, ...	24	× ¼	@ 20·04	= 1860
85·7	" "	24	× ⅜	" 30·06	= 2576·1
178·5	" bottom, ...	24	× ¼	" 20·04	= 3577·1
20·6	" tension and compression bars, sum of breadths,	35·5	× ⅝	" 74·1	= 1526·4
20·6	" "	4	× ½	" 6·68	= 137·6
20·6	" L iron compressed, ...	... 6 × 4	× ⅝	" 19·57	= 403·1
20·6	" "	... 5 × 4	× ⅝	" 17·5	= 360·5
20·6	" "	... 4 × 3	× ⅝	" 13·3	= 274·0
400	" L iron, top and bottom	... 4 × 3	× ½	" 10·86	= 4344·0
				Total lbs., ...	15058·2

dividing by 50, to obtain weight per foot run, we have the girder weight = 301 lbs. per foot run.

We also find that in 50 feet of span, the platform contains—

Cross beams, $7 \times 22 \times 1 \times 1{\cdot}13 = 174$ *c. ft. timber.*
Planking, $50 \times 22 \times {\cdot}417 = 458{\cdot}7$ "

Total cubic feet, ... 632·7

of which half, or 316·35, is carried by each main girder.

If we take the average weight of timber at 50 lbs. per cubic foot, we have the weight per square foot of platform $\frac{316{\cdot}35 \times 50}{50 \times 11} = 28{\cdot}7$ lbs., and therefore, we have $W_{bp} = 301 + 128{\cdot}7\, b = 8{\cdot}27$ tons, instead of 8·31 tons, as in our formula.

This* difference between the approximate and real data proves to be so slight that it is unnecessary to alter our design; had we been called on to do so, we should have multiplied the area of the several values of our girder by the ratio; $\frac{\text{actual } W_{bp}}{\text{provisional } W_{bp}} = \frac{8{\cdot}23}{8{\cdot}31}$.

For example.—The area of tension bar 1 would, in the case before us $= 8{\cdot}23 \times \frac{8{\cdot}27}{8{\cdot}31} = 8{\cdot}19$ (and the area of division XII. of the chords $= 33{\cdot}25 \times \frac{8{\cdot}27}{8{\cdot}31} = 33{\cdot}09$, had we found it necessary to correct them.

39. We do not—at least for the present—enter into practical details

* The rivets, packing pieces, and cover plates, &c., would very probably bring up the difference.

connected with the construction of girders; such as, "punching," "rivetting," "cover plates," "transverse bracing;" nor into the subject of "roadway platforms and cross beams." We have in our design used timber in this part of the bridge as being the most simple; but we might have adopted plate or lattice iron girders instead of the beams; and "buckled" plates instead of the planking, with considerable advantage, on the score of their greater durability.

The same principles exemplified in the design of our main girder may be applied to the case of lattice roadway beams; so that, the calculation of their proportions required no special example.

40. We can recommend—although we do not agree with him on many points—to those desirous of studying the subject of the practical construction of lattice girders, Mr. Cargil's paper in Vols. XXV., XXVI., of the Civil Engineers and Architect's Journal, beginning at page 303 of October number, for the year 1862. It is now, however, scarcely necessary for an Engineer to do more than hand an order to some of the great iron firms to construct a girder, of such and such a pattern, to bear such and such a load, in order to have the work properly done; but as it will be always well to have the power of testing the value of the design submitted, It is trusted that what has been now written may be found to have some practical utility.

John H. Hart.

TABLE OF SCANTLINGS OF BAR-IRON, AND THE CORRESPONDING SECTIONAL AREAS, TO ASSIST IN DESIGNING LATTICE BEAMS.

Breadths of bars in inches.	Thickness of bars in inches.							
	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1
	Areas in inches.							
1	·125	0·25	·375	0·50	·625	·75	·875	1·00
1½	·1875	0·375	·562	0·75	·9375	1·125	1·3125	1·50
2	·25	·50	·75	1·00	1·25	1·5	1·75	2·00
2¼	·2812	·562	·843	1·125	1·406	1·6875	1·968	2·25
2½	·3125	·625	·937	1·25	1·562	1·875	2·187	2·50
2¾	·343	·6875	1·03	1·375	1·718	2·0625	2·406	2·75
3	·375	·75	1·125	1·5	1·875	2·25	2·625	3·00
3¼	·406	·81	1·219	1·625	2·031	2·4375	2·843	3·25
3½	·437	·87	1·312	1·75	2·187	2·625	3·062	3·50
3¾	·47	·937	1·405	1·875	2·343	2·812	3·281	3·75
4	·5	1·000	1·500	2·000	2·500	3·00	3·500	4·00
4¼	·531	1·062	1·594	2·125	2·656	3·1875	3·718	4·25
4½	·562	1·125	1·68	2·25	2·812	3·375	3·937	4·50
4¾	·593	1·187	1·781	2·375	2·968	3 5625	4·156	4·75
5	·625	1·25	1·875	2·5	3·125	3·75	4·375	5·00
5½	·687	1·375	2·062	2·75	3·4375	4·125	4·812	5·50
6	·750	1·5	2·25	3·00	3·75	4·5	5·25	6·00
6½	·8725	1·625	2·437	3·25	4·062	4·875	5·687	6·50
7	·875	1·75	2·625	3·50	4·375	5·25	6·125	7·00
8	1·000	2·00	3 0	4·00	5·0	6·00	7·00	8·00
9	1·125	2·25	3·375	4·50	5·625	6·75	7·875	9·00
10	·125	2·5	3·75	5·00	6·25	7·5	8·75	10·00
11	1·375	2·75	4·125	5·5	6 875	8·25	9·625	11·00
12	·150	3·00	4·50	6·00	7·500	9·00	10·50	12·00
15	1·875	3·75	5·625	7·5	9·375	11·25	13·125	15·00
18	2·25	4·5	6·75	9·0	11·25	13·5	15·75	18·00
24	3·00	6·00	9·00	12·00	15·00	18·00	20·00	24·00

No. XCVI.

THE ALLAHABAD JAIL.

Specification of the several works to be done in erecting a new Central Prison at Allahabad.

FOUNDATIONS of all walls to be of concrete rammed in layers.

Plinths to be 1 foot 6 inches high, of kiln-burnt bricks set in mud.

Superstructure to be of height shown in sections, of sun-dried bricks, with a coping of burnt brick set in mortar and tiled.

Wall plates, 6 × 4 inches, for supporting the rafters to be used in all the buildings. All the doorways to be faced and arched with kiln burnt bricks set in mortar, and fitted with iron gratings; the vertical bars of which to be one inch square, and the horizontal ones $2\frac{1}{2} \times \frac{1}{2}$ inches at the least, and let into the pucka masonry 6 inches each way; no wood frames to be used.

The flooring of the barracks to be made of earth, with a 6-inch substratum of kunkur, or pounded bricks, well rammed.

The cases of the blowers used for ventilation to be made of pucka masonry, and the fans, &c., of iron. The main air-flues to be also of pucka masonry, 2 feet 6 inches × 1 foot 6 inches, or the size of the mouth of the blowers, diminishing in breadth to 1 foot 6 inches at the opposite ends, the height of 1 foot 6 inches to continue the same throughout. The branch-piping, leading from the main flues to the cells, to be made of earthenware pipes, 6 inches in diameter throughout, to the point where they join the end pieces for distributing the air in the cells.

The floors and angular drains of privies to be made of stone with carefully fitted joints, clamped with iron, and cemented with as little mor as possible.

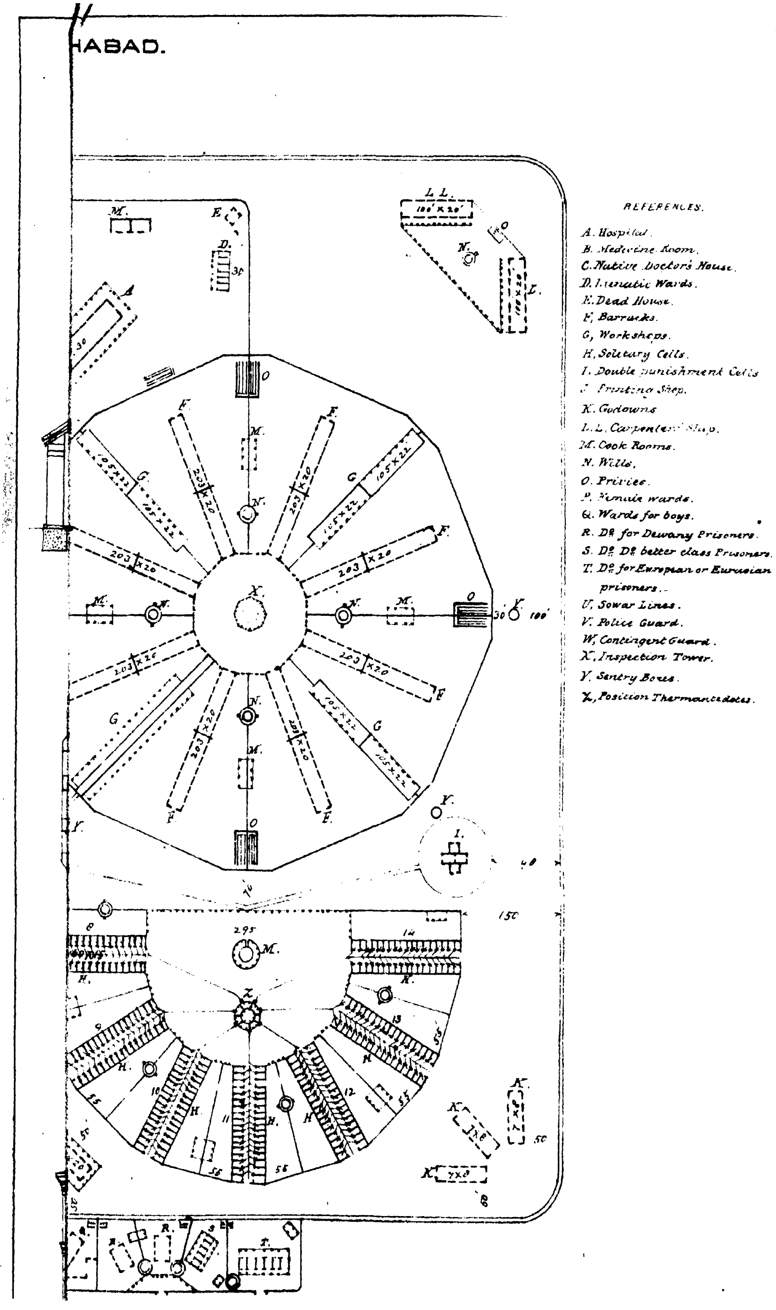
All the wood-work to be of good sál, sein, or other timber of eq quality and durability.

Convict labor to be employed where possible.

Estimated cost sanctioned by Government, Rs. 2,75,663.

S. CLARK.
Inspector General of Prisons, N. W.

NYNEE TAL,
The 12th April, 1861.



ABAD.
REFERENCES.
A. Hospital.
B. Medecine Room.
C. Native Doctor's House.
D. Lunatic Wards.
E. Dead House.
F, Barracks.
G, Workshops.
H, Solitary Cells.
I. Double punishment Cells
J. Printing Shop.
K. Godowns
L.L. Carpenters' Shop.
M. Cook Rooms.
N. Wells.
O. Privies.
P. Female wards.
Q. Wards for boys.
R. Do. for Dewany Prisoners.
S. Do. Do. better class Prisoners.
T. Do. for European or Eurasian prisoners.
U, Sowar Lines.
V. Police Guard.
W, Contingent Guard.
X, Inspection Tower.
Y. Sentry Boxes.
Z, Position Thermantedotes.

No. XCVII.

ROADS IN ASSAM.

Report on the Assam Trunk Road, by MAJOR BRIGGS, *Superintendent of Works in Assam. Dated 8th May,* 1863.

THE fair and fertile Province of Assam* has been endowed by nature with all the elements of a favored land, but these manifold advantages have been well nigh nullified by the absence of that union throughout its parts without which the very current of its life, so to speak, is unable to circulate freely. That its sub-divisions taken separately are thriving is undoubtedly satisfactory; but as long as there exists between them no connecting link, there can be no mutual benefits reaped, and the advancement of the Province as a great whole must needs be fatally retarded.

Some of the stations in Assam are unapproachable during the dry season, except by long travel through dense jungle. A steamer once in six weeks forms the sole means of intercommunication, the benefit of which, moreover, is only fully felt by the river stations. It takes longer to correspond between Goalparah and Dibrooghur than it does between Calcutta and Bombay. Dibrooghur or Luckimpore, with its hundreds of Tea Planters is, to all practical purposes, farther from the Presidency than any Civil or Military Station in Hindustan.

An erroneous impression prevails that as nature seems to have intended the Berhampooter as the great thoroughfare of Assam, therefore land communication is, if not unnecessary, at least of very secondary importance. Such is, however, a great mistake, which cannot long be entertained in the immediate presence of this mighty but unmanageable river. In fact, so

* Assam comprises an area of 34,345 square miles, and has a population of 13,00,000.

far from the country making the river subservient to its requirements, it is the river, as shown hereafter, which dominates the country.

That which is wanted to waken the Province into life and inspire solid strength is a road, running through the entire length of the valley, thoroughly open and passable throughout the whole year.

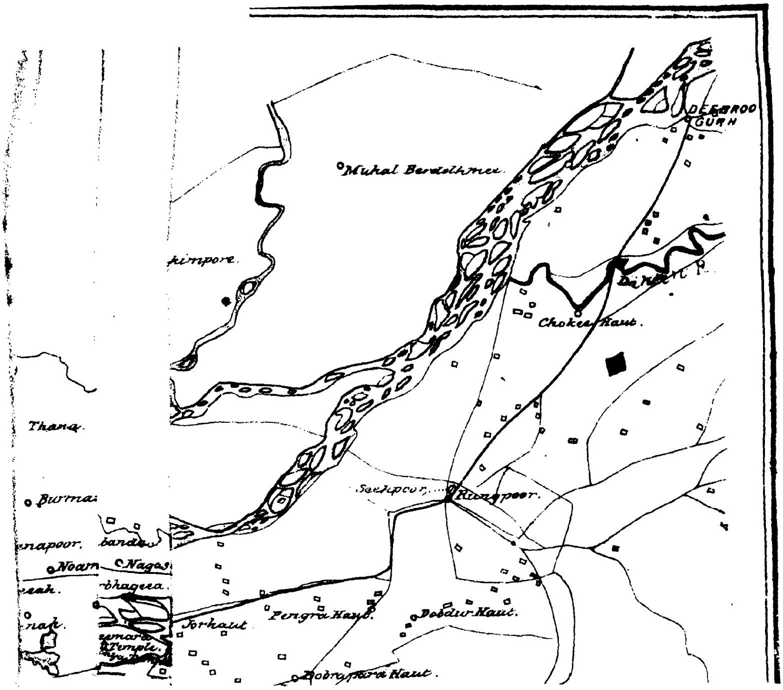
And surely the interests of the Province deserve it when every available acre of land is becoming the home of some enterprising Englishman, when it bids fair to rival the best Tea-producing provinces of China, and when the increase to the revenue of the Luckimpore district alone can be reported as amounting to three lakhs within the last four years.

Assam has been the Cinderella of the State ever since it has owned British domination. No province of British India but can show some public work to mark our rule; yet were Assam abandoned to-morrow, there would remain the traces of her old Rajahs in days of warfare and oppression, but not a single monument to the memory of England's more enlightened sway.

Savages though they were, these ancient rulers of Assam fully appreciated the incalculable advantages to the country of intercommuniction by land, and of restraint upon the incursions of the water. All their roads, *allees* as they called them, were constructed with this double object, as highways above the line of flood, and as bunds to control the inundations of their rivers. From above the spot where the Dihong and Dibong join the Berhampooter, down to the farthest confines of the Kamroop district, relics of their efforts remain, which, for bold engineering skill and a wonderful contempt of difficulties, deserve to rank with the works of the old Romans. Their lines of road were generally so well chosen as to direction, that if we can only afford to make the roadway as massive as their bold projects require, many portions of their works may be adopted. To unite their efforts with ours though years roll between us, and to complete, repair, and bring into use what internecine wars and foreign invasions prevented them from doing, has throughout a long and arduous survey been my constant endeavor.

In proceeding to report in detail on the line for the Assam Trunk Road, it will be well to look at the physical features of the country through which it has to pass.

Physical features.—The great feature of Assam is the Berhampooter. The cold weather discharge, immediately below its junction with its two



DEEBROO GURH
Muhal Berdolhmee
kimpore
Dehing R.
Chokee Haut
Thana
Burma
Seekpoor
Rungpoor
napoor
bande
Noam
Nagas
eah
bhageea
nah
Temple
Jorhaut
Pengra Haut
Doodur Haut
Dobrapara Haut

tributaries, the Dihong and Dibong, was found by Lieutenant Wilcox to be 120,176 cubic feet per second, of which the Dihong owned two-thirds. And at Gowhatty, 300 miles further down, it has since been found to discharge in flood 894,700 cubic feet per second, and in dry weather 318,200. At the same place the mean velocity was found to be 5·6 feet per second in flood, and 3·6 in dry weather. This mighty and impetuous river has at times swept over the greater part of the valley, laden with the wreck of mountains accumulated during the long course of itself and tributaries larger than itself. Through the Himalayas it rushes out of its rocky gorges upon the more level valley of Assam, where its diminished current permits the deposit of the vast amount of silt brought down with it. This deposit, settling in greater proportion along the banks where the current is slack, raises them above the level of the country, and with them, in due proportion, the whole bed of the river.

The effect of this upon the tributaries which descend from the hills confining the Valley of Assam, is to prevent their free discharge and to cause them to overflow the levels between the hills and the river. This is the case when the Great River and its affluents are equally in flood. But when as annually happens, the floods of the Berhampooter exceed in height those of the lesser streams, the currents of the latter are turned back, and the monster river rushes through the open channels and spreads over the level country, which in many instances, is 10 and 12 feet below the highest flood line. This may go on for ten or fifteen days, by which time the inundation is complete, and a great part of the Valley has become an inland sea.

As the river subsides, so the inundations commence to clear off the surface of the country, discharging through the channels by which they entered. This it is which renders Assam so unhealthy for several months after the subsidence of the periodical rains. The country has lain under water for weeks; the waters subside, leaving a rank vegetation covered with slime and mud to the action of a powerful sun.

Successive years of inundation through the same channels gradually widens them and prepare a fresh bed for the river, which, upon the occurrence of a sand bank in its old bed, it is not slow to take advantage of. Thus fresh channels of the Berhampooter are formed, and no two years find its course the same. Tradition gives at places a width of ten or twelve miles throughout which it has shifted its uneasy bed.

Besides the main channel of the Berhampooter there are other systems of drainage parallel to it, but in some cases removed from it by a distance of thirty or forty miles. These are always connected with the river at both ends, and are in fact inland channels. They are most valuable as lines of navigation for native boats during the heavy floods, because they present a more moderate current than the main river; such are the Kullung, the Gulahbheel, the Catre-Diphloe, and the Koolsee.

These, like the Berhampooter, and from the same causes, are lined with natural embankments considerably above the level of the surrounding country, and as their streams are moderate, these embankments are seldom breached or inundated. In the case of the Kullung, which runs for nearly a hundred miles through Central Assam, this natural glacis is so massive and high that the drainage of the country is by it forced back towards the foot of the hills, and not until it has accumulated so as to form a powerful river is it able to force its way into the Kullung. For fifty miles along the south or left bank, only three streams succeed in uniting with the Kullung. These broad embankments attract the populations of the country, and the banks of the Kullung form one vast belt of villages.

It requires no further argument to show that the banks of these interior channels of the Berhampooter must afford favorable lines for roads. These channels are also capable, at no very great expense, of being united and formed into a river canal, which might, with a few breaks, extend from the Dikoo river, in the Seebsaugor district, to Goalparah.

The chains of hills which confine the Assam Valley are prolongations of the Himalayas. That on the north is the most eastern spur of the outer Himalayas, which extend from the Indus to the Berhampooter, and it is occupied by the Bhootan and other hill tribes. That on the south is a spur of the Alpine range which separates the Valley of the Berhampooter from what Wilcox supposed to be the Irrawaddy. It is occupied by the Singhphos, Nagas, Cossyahs, and Garrows, besides other hill tribes.

From the lofty northern or Bhootan chain, descend many rivers of great size. From the southern or Cossyah range, which does not exceed 6,500 feet of elevation, the rivers, with three exceptions, are short. This points to the southern or left bank of the river as being more favorable for a line of road than the northern. It is therefore with the left bank of the river, upon which also the chief towns exist, that we have to do.

The geological formation of the chain which borders Assam on the south is generally of granite of a coarse and refractory nature. Occasionally sandstone occurs, and also some of the stratified rocks fit for building purposes.

In a few of the rivers of Upper Assam, and in some of those which issue from the Bhootan hills, limestone pebbles* are found but generally *scarce, while near the* Namba falls in the Meckir hills, crystalline limestone occurs; but the largest supply is obtained from the Digarro river, thirty miles above Sudyah on the Eastern Frontier, where the bed of the river is a mass of *lias* limestone nodules and boulders brought down by the water. Coal of good quality is found all along part of the southern range of hills in Upper Assam, and is brought down for the use of the steamers at something like 8 *annas* per maund.

The soil of the lower spurs and off-shoots of this chain of hills varies from red granular clay to that of a lighter and less retentive nature. As a rule, it produces the most luxuriant tree vegetation, including useful timber trees. At intervals considerable sál forests occur. But the humid climate of Assam forbids the use of timber to the Road Engineer.

On these spurs, or the plateau projecting from them, many of the most productive tea plantations of Assam have been formed; and cotton, as the main staple of cultivation, is produced by the hill people far up their flanks.

Selection of the line.—Sufficient has been already stated to show that in selecting the line for a road through the Valley of Assam, a wide berth must be given to the Berhampooter, where its banks are not sufficiently stiff to resist the action of the stream. At the same time, in many of the great plains at present subject to partial inundation, the road embankment might be made capable of controlling the inundations of the Berhampooter and so serve the double purpose of roadway and bund. This was successfully done by the old Rajahs of Assam.

When Rajah Roodroo Singh, upwards of a hundred years ago, commenced the present "Bor Allee" (great road), also at places called the "Dhodur Allee" (complete road), he designed it to oppose an impenetrable barrier to the floods of the Great River, as well as to afford the most direct line of communication between the important points of the country. It was never completed, but the portion between Jaipore and Jankanah

* Fragments of limestone rock, rounded by the action of water.

near Jorehath, about seventy miles, remains to show the stupendous nature of the work. From the height of the embankment it is visible two miles off. The width at top is from 35 to 40 feet. Its course is generally perfectly straight, and where there is a bend the curve is formed with mathematical precision. The trenches are dug with equal regularity, and never approach nearer than 100 feet to the road centre. So thoroughly has it reformed the water system of the country that in one place the whole drainage of thirty miles passes through four openings of about 100 feet each, and the sides of these openings have not been eroded by the passage of the waters for more than a century; the estimated area of waterway on a line parallel to this part and further inland was 718 feet, according to a former survey made. Only one of these openings was bridged, as according to present tradition, the Bengallee architect succeeded too well in pleasing the Rajah, who fearful of so acccomplished a person returning to Bengal, and affording aid to the British Government, caused him to be strangled.

The Jorehath people were most solicitous that the line of the Bor Allee should be adopted for the Trunk Road, and predicted the greatest benefit to the country. They thought the adoption of any other line unworthy of so great a Government when their own Rajahs had successfully constructed a portion of the " Great Road. "

I shall be able to adopt about fifteen miles of the existing Bor Allee, and propose extending it to Nigriting, where the Great Jorehath Plain ceases. This will present a barrier to the inundations from Seebsaugor to a point thirty miles west of it. At various other places, as along the banks of the Kullung, in the Nowgong district, and also westward of Gowhatty, I have selected the line of road with reference to the control of the inundation, where such selection does not interfere with the safety or utility of the road. Of course ample waterway has been provided for the passage of the waters of the interior. It is only sought to prevent the ingress of the Great River. I had in view at one time the fixing of regulating gates on such bridges, through which the river floods pass; but, considering the establishment which would be required to attend to them, am now inclined to think that, with the exception of three places, it would be premature. They are not, moreover, easily fixed on the wrought-iron girder bridges, which as shown hereafter, are, I am clearly of opinion, most applicable to Assam rivers

For other principles which have either guided or controlled me in the selection of the line, it will be best to refer to the Map accompanying this Report, and to the detailed description of the line mile by mile. Suffice it here to say that the total length of the road from Dibrooghur to Dobree will be about 354½ miles.

Roadway.—The roadway is to be everywhere not less than 2 feet above *highest flood line. It is to be 24 feet wide*, with slopes of 2 to 1. A berm 10 feet wide is to be left between the foot of the slopes and the trenches; where subject to inundation, the slopes will be turfed.

That the roadway may be available, if hereafter required, for a "light railway," no curve of less radius than 1,000 feet, and no gradient more than 100 feet in a mile, will be permitted.

I have made no provision for metalling the roadway, as I think the great object at present is to get the earthwork and bridges finished.

Bridges.—In the estimate, provision has been made for bridging all but two streams, the Diheen and Dhunseree, the first 560 feet, the second 500. The largest river I propose to bridge is 320 feet broad. Without bridges a road in Assam is useless; it would be better to bridge the rivers and leave the formation of the roadway for a future time than to form the roadway and neglect the bridges.

The sub-soil of Assam is generally favorable to the construction of foundations, and, except in a few instances in Upper Assam, where swamps occur, we find stiff and impermeable clay a few feet below the surface. It being the middle level of the country through which runs the line selected, we approach the streams where they are neither shallow sprawling torrents as when they first issue from the hills, nor broad shifting channels as when they enter the Berhampooter. We have generally been able to take them where they have deep beds, well defined banks, and a steady regimen of their own.

From the adoption of this middle level for the line of road, we greatly reduce the number of bridges which would be required if the road ran immediately under the hills, as *there* the numerous streams have not yet formed rivers; and we have also to deal with water in a much less formidable state of motion, for the great swamps which lie under the hills receive these streams, spread them over a great extent of country, where evaporation and absorption diminish their discharge and prepare them to drain off quietly through the middle level into the Berhampooter. I found that in the examination of two lines between Gowhatty and Goalparah, one-third less of running feet of waterway was requisite on the middle line than would have been required on a line close under the hills. I do not say that less *area* of waterway was required, for in the one case the bridges must be sufficient to afford passage for a great depth of water moving at a steady pace, whereas in the other, the bridges would require to be of a class suited to pass shallow but impetuous torrents flooded to excess during the rains, and nearly dry the remainder of the year.

The scarcity of skilled and even ordinary labor in Assam, renders it imperative that all means be used to economise it. I propose with this view to use wrought-iron girders and light abutments in all cases where the span is greater than 15 feet. In every way the iron girder bridge is the most suitable for Assam, as it affords the largest amount of waterway when the country is under inundation, and a free passage for boats—a necessary condition where all streams are used for navigation as long as water remains in them.

Culverts up to 15 feet span will be built of stone or brick masonry on the standard plan, provision being made for the greater height of abutments required in the deeper nullahs, and for a width of 24 feet between the parapets.

The wrought-iron girders and screw piles should be made up in Calcutta, and there is water carriage from thence to the site of every considerable bridge on the line; they might be placed on board lighters fitted with derricks and appliances, and so put up without the expense of establishing workshops at the site of each bridge.

I strongly advocate all these arrangments being made in Calcutta, either by contract or otherwise, as it would save the necessity of getting up expensive iron work establishments here.

Messrs. Knight and Co., have sent me a schedule of the cost at which they would put up all bridges above 40 feet in span on the wrought-iron lattice girder principle, with masonry abutments, and intermediate piers of cast-iron screw piles. I calculate their rates to be twenty-five per cent. higher than what the work might be done for by the Department; but my calculation is based on the supposition that the whole of the iron work is supplied at £20 per ton, and that all parts of the bridges will be fitted in the Government Establishment in Calcutta, freight being charged at Rs. 25 per ton to site of bridge. There is no doubt Messrs. Knight and Co., would do the work more expeditiously than if left to us, as the formation of the roadway and the culverts will engage all the labor I can possibly obtain for at least three years.

I do not recommend the use of timber for bridges, except as a temporary expedient. This climate will cause the decay of the best sál timber within four years.

Shelter.—At every twelve miles it is proposed to build a Bungalow to afford shelter to the Overseers of the section whilst the road is under construction, and to Travellers when the road is completed. A good waterproof roof with flooring raised on posts, and mat walls will be quite sufficient.

Jungle.—As the line runs through dense jungle for nearly one-third of its length, the cost of clearing it will be considerable.

It might be possible to provide for the thorough clearing of the ground on either side of the road by giving it for a breadth of 100 yards to settlers free of cost or rent on condition that they keep it cleared. This can only be arranged through the Civil Authorities.

Establishment.—I have supposed the road to be divided into twelve sections of about thirty miles each.

I think it will be necessary to appoint a Sub-Engineer to every two sections, and two Overseers or Assistant Overseers to every section. Thus six Sub-Engineers and twenty-four Overseers would be required to push on the works with vigor, and, in advocating such vigorous progress, I would beg that it may be borne in mind that the working season in Assam is only six months in duration, when, if great progress be not insisted on, such a work as the Trunk Road may drag along for years.

Rates and Contracts.—The experience of the past year forbids my estimating the cost of earthwork at less than Rs. 3 per 1,000 cubic feet, and masonry at from Rs. 15 to Rs. 18 per 100.

Iron work is taken at the prices named by the Chief Engineer in his Memorandum of the 2nd February last, with carriage from Calcutta added at Rs. 25 per ton, and erection at 20 per cent upon cost.

I strongly advocate every means being tried in Calcutta to effect the greater portion of the work by contract; and I think some 300 millions of cubic feet of earthwork should attract some of the Railway Contractors now out of employ.

But to effect arrangements with them the appropriation of at least four *lakhs of rupees per annum for the work is an absolute necessity.* With such a sum, operations could be commenced opposite Doobree, in the vicinity of the Rangpore district, where almost any amount of labor can be obtained, and advanced on a scale commensurate with the magnitude of the undertaking.

Estimate.—The estimates for the entire road with bridges over every stream, with the exception of the rivers Diheen and Dhunseree, amount to Rs. 21,29,558.

I will now proceed to describe in detail the several sections of the line.

SECTION I. *Dibrooghur to Seebsaugor*, 41 m., 3 f., 200 yds.—The present existing road between Dibrooghur and Seebsaugor is one of the old Assamese "Allees," not very straight but raised generally above the flood line. Its adoption for the Trunk Road is a matter of course. It will be only necessary to round off the turns, to widen it, and to complete the section of the road to a uniform height of 2 feet above possible inundation.

For many miles the road is at present impervious to the sun-light from the dense mass of surrounding forest, and it is consequently damp and unfavorable to traffic. All but an occasional fine tree will be removed to the distance of 100 feet on either side of the roadway.

Between Dibrooghur and Seebsaugor all culverts have been already provided for, and about twenty are either completed or well advanced.

At the 15th mile from Dibrooghur occurs the Sessah river, with a section of 100 × 20 feet, having stiff clay banks well defined and a hard sandy bottom. A wrought-iron lattice bridge of two openings of 60 feet each and light abutments is provided for in this estimate.

At the 28th mile the road strikes the Diheen river immediately below where the Diheen-Sutee enters the Burra-Diheen. It is from 560 to 600 feet wide, with light loamy bed, and banks covered with grass and forest. The depth of water during the cold season is not less than 4 feet, and it is consequently navigable for boats all the year. Rising in the distant country of the Singphos, it is a great river during the rainy season, in fact, the largest on the left bank of the Berhampooter. The only means I suppose for facilitating the crossing of this river is by good ferry boats, and reducing the ghâts to an easy slope.

Nine miles further on is the Demoo river, 110 feet wide, with sandy bed and stiff clay banks, well defined and not subject to inundation. For this a bridge similar to the Sessah has been provided in the estimates.

At six miles from Seebsaugor is the *Disang* river, with an area of 300 × *25 feet.* Its beds and banks of a loamy sand. It has 4 to 5 feet of water in it in the dry weather, and is a very difficult river to cross after rain. I have provided a wrought-iron lattice bridge of five spans of 60 feet each.

SECTION II. *Seebsaugor to near Jorehath,* 36 m., 0 f., 150 yds.—Seebsaugor is remarkable for the extraordinary artificial lake round which it is built. This lake is two and a half miles in circumference, and the surface of its waters in January measured 28·26 higher than the surface of the waters of the Dureeka nullah close by, that is about 20 feet above the level of the surrounding country. The lake is connected with no ground of superior elevation, and has therefore no supply channel. I could learn of no known springs, so that its waters must be the accumulation of rain only.

Close by to the westward, flows the Dikoo river, 300 feet wide, for which a bridge is estimated to be built under the town; and beyond is the famous Bor Allee or Great Road of the Assam Rajahs, which extends, with occasional breaks, from Jaipore to Jankhanah, where it ceases incompleted.

It is from 35 to 40 feet wide at top, and 20 feet above the level of the country. It has few openings, for its design has been to throw all the minor streams together and afford them passage in one volume at intervals of four, five, and eight miles. This is easy on account of the dead level of the country. In places it has been considerably worn by the constant passage of large herds of cattle which, during the floods, have made it their abiding place for a century. I received many petitions from the Mouzadars of the district praying for the adoption of the Bor Allee as the Trunk Road, because that would ensure its completion and its future repair.

Their interest in the Bor Allee is as a bund to the inundations of the Berhampooter. If completed it would rescue tens-of-thousands of acres for cultivation, and greatly improve the revenues of the district. I am myself much in favor of its adoption as a noble work, which it is worthy of the Government to complete, especially as it offers a considerable saving in distance and no great increase in expense. Four bridges of two openings of 60 feet each, and two of 60 feet, will be necessary to cross the river channels which intersect it up to the high land at Deargong.

SECTION III. *Near Jorehath to Dhunseree river,* 29 m., 2 f., 60 yds..—

Under the head of the last section, I have brought the description of the line up to Deargong, or over twelve miles of this section. At Deargong the line of the Trunk Road meets the Gohur Allee (or War-path of the Assamese), said to have been constructed in a single night during the Muttuck invasion.

It extends from Jorehath to the Dhunseree, and has a general width of 12 feet and a height of from 2 to 4 above level of country, which is sufficiently high to be removed from all chance of inundation, with exception of half a mile near Rangamuttee, where the embankment must be 10 feet high to keep out the back waters of the Berhampooter. Seven bridges from 20 to 60 feet span, and fifteen culverts, are required over this portion of the road.

Close to the Dhunseree, a branch road runs off to Golah Ghât, distant about seventeen miles, a good fair-weather road made by the Assam Rajahs. At the 29th mile from Jorehath is the Dhunseree river, 500 feet wide, with very steep sandy banks and a strong current, with about 5 feet of water during the cold weather. It is a very large and powerful river during the rains. We can do nothing for it at present but establish a good ferry and slope the banks to afford an easy approach.

SECTION IV. *Dhunseree river to Baguree*, 31 m., 3 f., 110 yds.—We have now entered on the plateau which lies between the Meekir hills and the swamps of the Berhampooter, the general elevation of which varies from 20 to 40 feet. It is thickly intersected with hill streams, the deep gullies of which are in many places subject to inundation from the Berhampooter for some distance up their courses. Along this plateau the Dhodur Allee holds its course. It is very straight with a general section of 12 × 2 feet. This Allee will be generally adopted for the Trunk Road. The soil is very favorable for road-making, and if the trench be always kept on the upper side of the road as a catch-water drain, a general average of 2 feet will be sufficient raising. Timber is abundant for fuel, and the Meekir hills will certainly provide road metal, if not building stone. This part of the country is but thinly populated as far as native inhabitants are concerned, but the wooded slopes of the Meekir Hills seem to have found favor with Tea-planters, whose gardens lie along the neglected jungle road which forms the obviously insufficient means of communication between the homes of these European settlers. It may

is supposed to

commence, and with it a tract of country remarkable for beauty of scenery even in a province so generally favored by nature as the Valley of the Berhampooter.

On the whole, this portion of the line, though hitherto more than usually neglected, has the advantages for road-making, of a straight line and fair general elevation, together with the possession of good stone for building and metalling ; but owing to its intersection by numerous nullahs the amount of bridges required will be large. The Diphole, Dering, and Koberah streams require bridges of 60 feet. For nine others, spans of from 15 to 35 feet will be requisite, and 67 culverts.

SECTION V. *Baguree to Bor Allee village.*—The first portion of this section lies through dense jungle : the inhabitants however of which despite their seclusion, are sufficiently aware of the advantages of traffic to desire that a "hât," or market may be established in the village of Baguree. Cotton in considerable quantities is brought down from the hills by the Meekirs. As we pass on, the line rises to a higher plateau and follows the water-shed line until reaching the Katoree levels, where a good many streams exist, which are liable to overflow in the rains ; of these the Daopanee is the largest and most difficult during flood. A little further on huge granite boulders form a curious feature in the scenery. The line thence continues, through jungle still, over the Diphloe river and sundry smaller streams till a difficult swamp is reached, which at present forms a nearly unsurmountable barrier to the traveller. It is about 280 feet across, but there is a narrower place where a bridge of 60 × 20, would probably suffice. A succession of small nullahs now ensues, averaging from 6 to 12 feet. At Rangloghur is a curious old Assamese embankment.

We here enter the fertile tracts in the neighbourhood of Koliabur, rich in magnificent crops of rice, sugar-cane, tobacco, mustard seed, &c., showing what cultivation can do for the naturally luxuriant soil of Assam. The Kullung river comes first under notice, the road following its banks so closely as greatly to endanger it. Villages succeed each other rapidly along this bank, but owing to the above-mentioned incursions of the river it will be necessary to carry the Trunk Road to the back of these villages. This will have the advantage of cutting of large angles formed by the present road following every curve of the Kullung, and the still greater one of forming a bund to save the levels behind the villages from inundation by that river. To prevent the Kullung, in the first instance, from rising so high as to flood the villages, the present road must be raised 2 feet as a bund only. The altered road will require three bridges of about 15 × 15 feet.

The entire number of bridges required in this section are two of two openings of 60 feet each, one of 60 feet, seven of from 20 to 30 feet, and 52 culverts.

Sections VI. and VII. *Bor Allee village to Nowgong, and the mouth of the Kullung.*—Immediately after passing Bor Allee village the Meesah river obstructs all ordinary traffic. It drains all the low country between Koliabur and the Meekir hills, and though not broad is very deep. A wrought-iron girder bridge of 50 feet is provided for it. Two miles further on is the Deejoo river of exactly the same character, but of greater size ; a bridge of 60 feet is provided. The banks are of hard concrete.

From this point to Nowgong station, a distance of eighteen miles, not a single stream enters the Kullung; two drains near Chummergooree being the only openings required.

As hitherto, the road continues to follow the left bank of the Kullung, and for eight or ten miles, before arriving at Nowgong station, passes along a fine broad avenue of noble trees, lined with habitations and gardens on the inner side, or that opposite the river. The scene reminds one of the approach to Hooghly. Unfortunately the old danger of the road being destroyed by the river exists here in full force, and will necessitate the taking further back of the Trunk Road ; but the present opportunity has not been lost sight of for repairing the old road, so as to form a better bund and prevent the water getting between it and the Trunk Road, which would flood the houses and gardens. After reaching Nowgong by the left bank of the Kullung, as already mentioned, the road crosses the river, re-crossing twenty miles further down. I was anxious, however, to continue on the left bank without crossing, and therefore examined the Kullung down to its mouth, a distance of seventy miles, but found that such a course would entail the crossing of seven rivers requiring bridges of considerable span and a large number of smaller bridges and drains.

The Kullung bridge near its dèbouchure will have a centre span of 200 feet with two sides of 60 feet each. It will be well raised above ordinary level so as not to interfere with the navigation of the river. The bed of the river for half the way across is of rock, and the remainder of stiff clay: good building stone is on the spot.

The dry weather depth of water in centre of river is 38 feet. The depth when in flood is 64·16 feet.

The greatest length of pile will be 60 feet, which will give 10 feet for sinking in bed, and 19 feet above high water mark.

It must be clearly understood that without this bridge over the Kullung, the line I have selected between Nowgong and Gowhatty cannot be adopted, as this river would prove an insuperable barrier to easy communication. A ferry would be most inconvenient, and the stream is too strong for a bridge-of-boats. But the substitution of any other line would, from the enhanced distance and number of streams, greatly exceed the cost of the selected line, inclusive of the bridge. Moreover, by this line we avoid the Ghâts which occur on the old pathway within twelve miles of Gowhatty. The run in from the bridge to Gowhatty will be nearly level, and will adopt for some distance an old embankment of the Assamese.

SECTION VIII. *Kullung river to Gowhatty and Pulasbaree.*—As above stated the line from the Kullung to Gowhatty presents no difficulties, a bridge fitted with regulating doors over the Bundajan to prevent the flooding of the country and a few culverts, being all that is required.

In the station of Gowhatty a similar bridge over the Bhoroloo, to prevent the flooding of the low lands at the back of the station, and another over the Kulbogh Nuddee at Pulasbaree, are all that is required in this section.

Eight miles of road and a bridge of 55 feet span over the Khanajan have already been completed, or are in process of completion under a former estimate.

SECTION IX. *Pulasbaree to Chokchokee.*—For several miles in the neighbourhood of Pulasbaree the line follows the high bank of the Berhampooter, but sufficiently retired for safety, and to obviate the destruction of the numerous villages which line the bank of the river. It then passes off to the foot of the outlying spurs of the Garrow hills, being unable further to follow the river bank, which soon after sinks into a succession of sand banks extending to Nuggerberah near Goalparah, over which the Berhampooter rolls during floods.

In crossing from the river banks to the higher ground under the Garrow hills, a difficult river, the Koolsee, is met. It is chiefly difficult from the shallowness of its bed, rendering it liable to shift and divide into several channels. The exact spot for crossing this river must be left until I can examine it in flood, but in the meanwhile I have provided for bridges over two channels, which it seems inclined to abide by. No other bridges and but few culverts are required until the foot of the hills is reached, as the country is a dead flat; and although the earthwork will be heavy, it will be invaluable as a bund to the inundation of the Berhampooter.

The road will not ascend any of the Garrow hills, but be carried from spur to spur, crossing the numerous torrents which flow from them after they have united in a few considerable streams. From spur to spur the earthwork will be rather heavy, but here again in many places it will protect the country from the inundations of the Berhampooter. The Singrai river is crossed in two channels, the eastward requiring a bridge of two openings of 60 feet each, the westward one span of 60 feet. Nine other bridges of from 50 to 20 feet span are required and fourteen culverts. *Granite is available all along the line at a moderate distance.*

SECTION X. *Chokchokee to Salparah.*—Great difficulty was at first experienced in examining and determining the line throughout the last section and the first portion of this. The result, however, was successful, for, whereas the present track crosses sixty-five streams, four of them varying from 120 to 300 feet in width, the selected line crosses only thirty-four, the largest of which requires merely a bridge of two openings of 60 feet each. There is also a saving of four miles in a distance of forty.

At Koontabaree, the Goalparah district is entered after passing through a belt of high grass jungle three miles in width, and crossing the Daoselah river, the line enters the thickly populated Bamunee valley, and onwards through the large villages of Amjongah, Khurrah, and Mundalgaon to Salparah. The chief difficulty is the Doodnee river, flowing from Damrah under the Garrow hills. The shallowness of its channel renders it liable to overflow, and I could find no spot where it is self-contained. I believe however, that three openings of 60 feet each will suffice, with two culverts of 15 feet each on the inundated flats right and left of the river. Beside these six bridges of from 30 to 60 feet span, thirty-four culverts are required in this section.

SECTION XI. *Salparah to Luckipore.*—This section is generally through high-lying ground here and there covered with sál forest. The line passes Goalparah about twelve miles to the right, to which place a branch road can easily be made. I attempted to take the line through a part of the Garrow hills to cut off the long Agneeah spur, but after trying many routes was obliged to give them up, as they proved too steep, and I have fixed on a line skirting the south of the Orpud lake, and running through a defile east of Agneeah village. The Krishnai and the Jinaree, are two considerable rivers crossed in this section, but they have fine deep sections, and with relieving culverts right and left can be safely bridged with three openings of 60 feet each for the Krishnai, and two of the same span for the Jinaree. Towards the end of this section heavy earthwork will be required on the Metchaparah plain, as it is liable to inundation.

In all, besides the rivers above-mentioned, seven bridges of from 20 to 60 feet span and twenty-six culverts will be required in this section.

SECTION XII. *Metchaparah to Berhampooter, opposite Doobree.*—This, like the latter part of the last section, is low and liable to inundation, intersected by a number of jheels and old channels in which water has no current. I have allowed for 600 feet of waterway in the eleven miles and for filling in all the old channels.

Waterway is provided by one bridge of three openings of 60 feet each over the Garrah river, one of two openings of the same dimensions over the Khunia, and four of one opening of 60 feet over other inundation channels.

At Khunia village the Berhampooter is met with, Doobree lying on the farther side, and at this point ends the exploration and survey of the Assam Trunk Road.

To sum up the results arrived at; the road will be about 355 miles in length. It is impossible to give the *exact* length of its course through swamp, grass and forest. The Earthwork required is 361 millions of cubic feet, which will probably cost Rs. 10,84,609.

The area of waterway allowed is 143,438 square feet, which, with a mean velocity of four miles per hour, would suffice to pass the whole Berhampooter.

To cross this waterway I have provided twenty-one wrought-iron lattice Bridges of from two to five bays of 60 feet each, at a probable cost of Rs. 3,88,349.

Fifty-eight similar bridges of single spans varying from 20 to 60 feet, at a probable cost of Rs. 2,64,900.

And two hundred and seventy masonry culverts from 4 to 15 feet wide, at a probable cost of Rs. 3,00,000.

Twenty-eight temporary Bungalows for shelter, will cost Rs. 8,400.

Eighty-five millions of superficial feet of jungle clearing is estimated to cost Rs. 83,300.

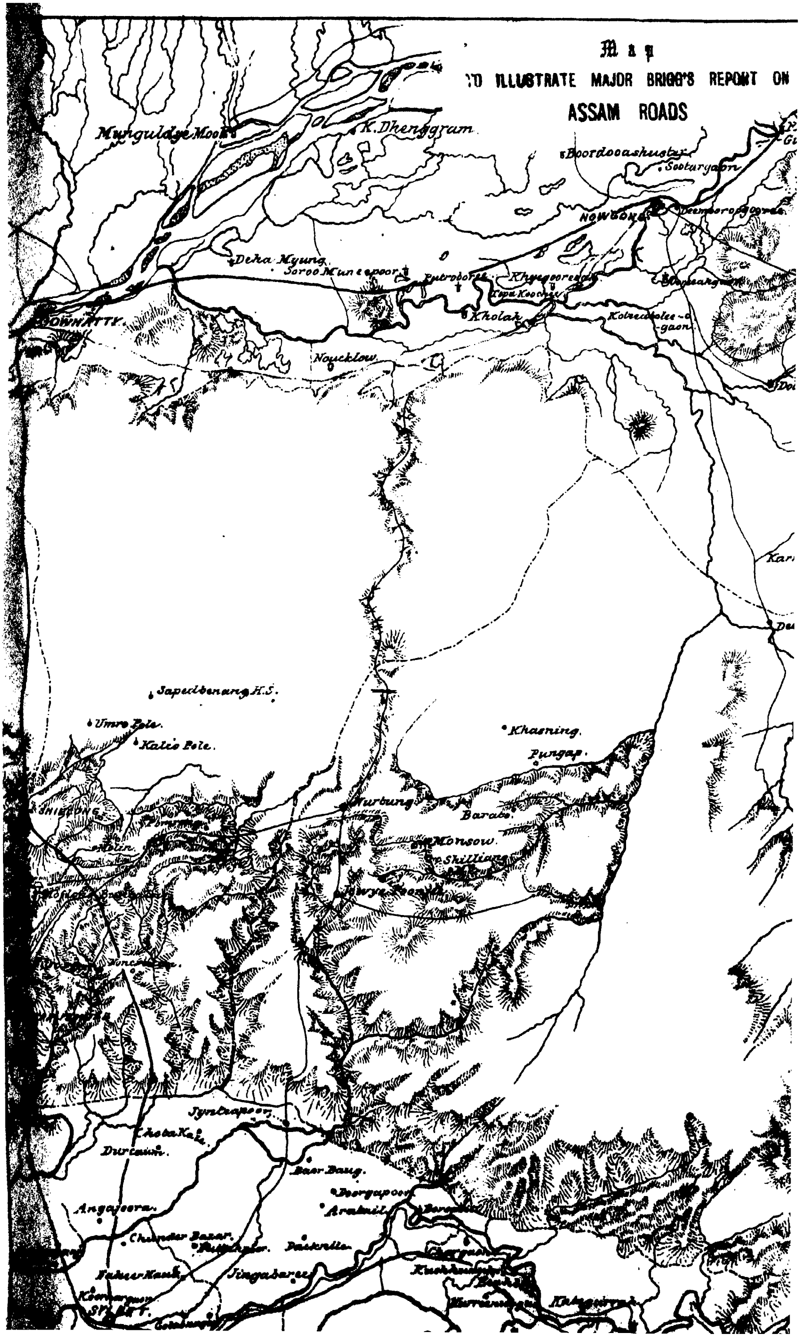
Thus the total cost of the road with bridges over every stream, excepting the Diheen and Dhunseree, will probably be Rs. 21,29,558, or Rs. 6,000 per mile, and the work might be completed by the end of 1867, provided the necessary funds are forthcoming at required seasons.

In the estimate I have been unable to provide any sum for compensation for land taken up for the work. If a fair arrangement can be made for the disposal of waste lands to be cleared of jungle on either side of the road, they should amply balance the amount of compensation due for cultivated lands encroached on by the road.

THE country lying between Gowhatty and the main axis of the Cossyah Hills, of which Shillong is the crowning height, was only known to Europeans along the Nunklow hill-path, and this was held in so bad repute from its unhealthiness, that those who ventured the journey along it did so as fast as the means at their command permitted, and considered themselves fortunate if they escaped the malarious fever which, undoubtedly, pervaded it at almost all seasons of the year. This route was wholly unadaptable to a line of road with gradients not exceeding 1 foot in 25.

Another route to the eastward was known to a few Officers, and was recommended in 1862 for adoption as the future hill road between Gowhatty and Shillong. But I found it generally so deeply imbedded in swamps and low bottoms that for this and other reasons given in my letter of the 20th November, 1862, I strongly declared against its adoption.

It seemed to me that as both of these routes were intersected by streams flowing in opposite directions from a range of hills lying between them, and that as this range abutted on the plain close to Gowhatty, I should in all probability find that a line of road might be taken close to its watershed, which would ensure a higher and healthier route, the absence of all large rivers, and probably afford a natural inclined plane sloping upwards to the great elevated plateau of the Cossyah Hills. It will be seen that in these qualities my surmises were found to be generally correct.


Map
TO ILLUSTRATE MAJOR BRIGG'S REPORT ON
ASSAM ROADS
Munguldye Mooh
K. Dhenggram
Boordooashustar
Sooturgaon
NOWGONG
Deha Myung
Soroo Muneepoor
Putroborch
Kholah
Kolreeabolee-gaon
Noucklow
Sapedbenang H.S.
Umro Pole
Kalo's Pole
Khasning
Pungap
Nurbung
Barabo
Monsow
SHILLONG
Jyntiapoor
Durcaun
Baar Baug
Angajeera
Chunder Bazar
Daikrille
Jingabaree
SYLHET

Although I have spoken of a range of hills lying between the two routes, it must not be supposed that this is a peculiar feature in the aspect of the country. So far from it, the whole of the space between the Cossyah Hills, properly so called, and the Valley of Lower Assam, is crowded with a mass of rounded hills apparently detached, but in reality (following the almost invariable law of physical geography) joined by low and narrow passes. The tops of these hills vary from 1,500 to 3,500 feet above the sea level, and their connecting links or passes, which become obligatory points to a road taken in the direction of the axis of any one of them, vary from 1,800 to 3,000 feet, the height increasing as the axis nears the mass of mountains from which it has been thrown off.

The appearance of these hills when viewed from the superior range of the Cossyahs is like a tumultuous but unbroken sea, no wave rising above one normal level, but no portion absolutely smooth. Where the general elevation is below 2,500 feet, the hills are covered with dense bamboo and tall grass jungle. The sál, jamoon, gumree, and semel are the common forest trees. Above that elevation bamboo generally ceases, and, except in the bottoms, the grass is of moderate height, and a pine very similar to the Scotch fir becomes the ordinary forest tree. Above 3,000 feet oak becomes common. I am inclined to associate the fever level with that of the pine.

These hills, with an exceptional wall of cliffs, or granite crags exposed by the action of water at their base, are well covered with soil, generally of a rich red quality of that kind favorable, I believe, to the growth of Tea. This depth of soil presents to the Engineer fewer natural obstacles than are generally met with in the construction of hill roads. It is also of a nature which promises to preserve its form when the section of a road 24 feet wide is cut from the hill side.

Throughout this undulating mass of hills there are but few villages. Five and six miles may be passed without the traveller seeing one, yet at almost every mile there are vestiges of former habitations, deserted, it is said, in consequence of the ravages of wild elephants. The crops of hill rice, pulse, and cotton, which are here and there met with, are all fine in quality, and the specimens of the latter were the heaviest bolls I have seen in Bengal. Unlike the distinctiveness of race and language which characterise the peoples of the mountains shutting out the Valley of Assam from the south, the population of these lower hills is of a mixture of tribes.

The Garrow, Meekir, Cacharee, and Cossyah are found here all living together, and although not so powerfully made as the true Cossyah, yet the mixed race is a fine one and marvellously superior to the lazy and effeminate people of Assam. They are quiet, good-natured, fond of home, and far more temperate than the inhabitants of the higher hills. They are great woodsmen, using the *dhou* with admirable facility, but are destitute of the means of waging war against the wild animals from which they suffer. As a rule, they have neither guns nor bows, and the art of snaring or trapping, so well understood by neighbouring tribes, is to them almost unknown. This is the more curious, that they are great admirers of flesh, and are quite without prejudice as to the kind, quality, or condition. A morsel of an elephant found dead on their hills, or a succulent puppy bought at the Bengallee *haths*, are equally prized delicacies.

Having dwelt somewhat at length on the description of the country between Gowhatty and the Cossyah Hills Proper, because it is a region hitherto unknown to Europeans, I will not give a separate description of the well known ground of the Cossyah range, but merely notice such parts as affect the line of road, when describing its course with reference to map and section.

Attached is a section of the entire line of road from the Berhampooter at Gowhatty to the Soormah at Sylhet. The heights were taken by Aneroid Barometer compared with the standard in the Surveyor-General's Office in Calcutta; and the distances, partly by actual measurement, and partly by computation of the length of base, corresponding to the observed difference of height proceeding at a known gradient. In many places the jungle was so dense that the line could not have been measured without a clearing being first effected, and that would have delayed me far longer than my other duties could permit. A map on a scale of 4 inches to the mile showing this line of road and all new roads being constructed or surveyed within the circle, is now under preparation and will be forwarded when ready. In the meanwhile the Cossyah and Jynteah Hill map will serve the purpose of this Report.

After passing through six and a half miles of the Assam Plains to the south of Gowhatty the line ascends 950 feet, at a gradient of 1 foot in 25 for four and a half miles, with a level break of half a mile. The line then descends 250 feet to the Gorbungah Valley, which lies between the last high Station and the Kukra Seel Pass. This descent is easily effected at a gradient of 1 foot in 40. But when the ultimate point to be reached was still upwards, this descent is, of course, contrary to the true principleso n which hill roads should be laid out, as the Engineer has no right to impose on the traveller the double ascent of so many hundred feet. The choice lay between winding for six miles up and down a lateral valley, or introducing the easy gradient of 1 in 40 for a mile and a half down and a mile and a half up to the Kukra Seel Pass, and the latter course was preferred. For the same reason the abnormal descents at the 22nd mile, the 36th mile, and the 49th mile, became necessary to avoid an increase of distance of some eighteen miles.

After a short descent of 1 in 33 from the Kukra Seel Pass the line proceeds at a very easy gradient through long flat valleys to the Oomur Nuddee. On either side are hills covered with the unrivalled forest growth of Assam, and here it is that the soil is of so excellent a quality for the growth of tea. The line crosses several small streams, tributaries of the Oomur, which is crossed at a spot easily bridged, where its crystal stream dashes over a ledge of rocks; and this site has been selected for the first Inspection Bungalow. The valley is well stocked with magnificent sál trees, and being at a general elevation of more than a thousand feet, is always comparatively cool.

Between the Oomur and the Amtenah streams, a rise of 150 feet at 1 foot in 33, and a corresponding descent is necessary to cross a small intervening range on which cotton and hill rice are cultivated. The Amtenah will require a bridge of 70 feet span, the largest on the whole line of road until the Sylhet Plain is reached.

From the Amtenah the line recovers the watershed by ascending for three miles, at a gradient of 1 in 33, to the obligatory Pass above Punkir village. It passes through rich red soil covered with forest presenting no difficulties. Here it meets the head of a long flat valley which extends down to the old Nunklow road near Nowgong, and which some twenty years ago was covered with cultivation. The annoyance the villagers met with from wild elephants caused its abandonment; but now, in consequence of the large clearings the road will require, its re-cultivation is confidently looked for. Crossing the head of this valley to a series of obligatory points on the watershed line, it passes along them at easy gradients and level spaces until it strikes the Oomloor river near its source close to the village of Palliar. Here, at 2,200 feet above the sea level, the first pines are met with, and from this the natural growth changes from dense bamboo jungle and lofty grass to comparatively low grass, and an entire absence of bamboo and other plants characteristic of the Assam jungles. Two miles beyond Palliar, at an elevation of 2,500 feet, we are building the second Inspection Bungalow from Gowhatty, and I believe the spot will prove generally healthy and above the limit of the fever stratum.

Having reached 3,000 feet we are obliged to descend at 1 foot in 60 and 1 in 100 to the next obligatory point on the watershed, (elevation 2,772 feet) from which we run up easily to the crossing of the Putran stream, the eastern tributary of the great Borpanee river which flows under Nunklow. It will require a bridge of 65 feet. The descent is through beautiful glades, bounded by grassy knolls, on which magnificent red barked pine trees cluster in groups, more pleasing to the eye than art could ever have devised. If this mass of swelling uplands proves as healthy as the appearance of the few inhabitants promises, and as my native predilections in favor of the healthful atmosphere of the pine suggests, another wide field in the waste garden of Assam lies ready to repay the industry of the English settler.

The ascent from the Putran stream to the first terrace of the Cossyah Hills Proper, forms the longest incline on the road, at a gradient nearly approaching 4 feet in 100, which Government was pleased to fix at my suggestion as the maximum. The incline varies from 1 in 33 to 1 in 25 and is twelve miles in length. To have eased the gradient would have added to the length of the road, which I thought objectionable. These twelve miles lie through a magnificent forest of pines, many of which attain great size. Although there are some stiff rocky banks to be cut into for the full section of the road, yet, except at one spot, there is no continuous line of cliffs. The exception is where the line cuts a wall of granite about 200 feet in length, at 40 feet from its top. In two places narrow spurs will be cut down 30 feet, and at the top of the pass there will be 20 feet taken off its height. Here, at an elevation of 5,222 feet, the third Inspection Bungalow will be built. The two already adverted to are being built in the ordinary Assam style of thatched roof on posts, with bamboo mat walls and flooring, costing about Rs. 250 each; but such will not do at this elevation. Good rubble stone walls, chimnies, and planked flooring are required; and it is hoped that Government will sanction Rs. 1,500 for each Bungalow in the Cossyah Hills, as it is impossible for the Road Officers to live in tents during the greater part of the year without losing their health; and, as a matter of mere economy, it is cheaper to provide weather-tight accommodation than to have them frequently unfitted for duty through sickness.

After reaching the top of the Pass, which I will call that of Nongrimchitla, (for the village of that name is within 2½ miles,) we enter upon a country of long flat valleys and bare ridges, grim and sterile in appearance during winter, from the almost total absence of trees, but during spring and summer spread with a richly tinted carpet of wild flowers and berries. Where, too, the soil is best, hundreds of acres of potatoes show its richness by their luxuriant growth, and prove the fitness of the climate for European crops. The cattle also, by their size and sleekness, evince the nutritious property of the natural grasses, and suggest speculation as to the weight and quality of the beef they might produce if stall-fed in winter with the turnip, which the potato land would undoubtedly supply.

The flat valley country extends, with only one interruption, for ten miles in the direction of the line of road, and widens out to great breadth in the neighbourhood of the village of Marpana, stretching up on the broad flank of Dinghai, which rolls up its massive out-line in the eastern horizon to a height only 370 feet less than Shillong. The one interruption alluded to is the second terrace of the Cossyah upper plateau, the rise from 5,200 feet to 5,600 feet. Except in temperature there is no difference between the two, therefore I have described them as one. This rise is arranged at a gradient of 1 foot in 27 along the face of a hill presenting no special difficulties.

Under the village of Marpana, the road shoots through a chasm formed by the river of that name, and this will constitute one of the most picturesque parts of the line. The river rushes from one flat valley to the next, through a narrow opening between two ranges of cliffs, so narrow that it is not seen until the gorge is entered. From the cliff on the left bank the road will be cut, crossing the river where it turns sharply to the east by a bridge of about 50 feet span. It then gently descends at 1 foot in 33 to a highly cultivated valley, which it first touches, and then slips over a low pass into another fine valley leading to the Kuksee Nullah.

The Kuksee, lovely as a Devon brook in its clear deep pools and sparkling runs, its mossy banks glowing with wild flowers and the bright straw-

berry, with here and there a rugged rock to force its calmer beauties into stronger contrast, bounds the last of the open valleys north of the "Wailing Waters," the rock-bound and terrible Oomeeam. Through oak copse, birch, and rhododendron, the road gradually ascends to a pass 200 feet above the Kuksee, from which pass it winds down to the Oomeeam, crossing the river just before it is thrown into an abyss more than 1,000 feet in depth. In the ascent, a chasm of 60 feet has to be bridged, and in the descent about one quarter of a mile of very compact slate has to be cut through; otherwise no extraordinary difficulties occur.

From the Oomeeam, the line ascends at first at a gradient of 1 foot in 30 along the very precipitous hill-side which slopes down to the river. Here the excavations will be heavy for about one mile, but the rock is not compact, and will offer no great impediment to the work-people. Near the village of Marbeesoo the line joins the present road from Moflong to Shillong, about three miles distant from the western boundary of the station. At this point, after crossing a tributary of the Oomeeam, a fertile valley is followed up to the west flank of the Shillong mountain, the gradient being 1 in 55 and the distance four miles.

Having described the line as far as Shillong, I will state what work has already been done between it and Gowhatty, the cost, and our immediate requirements; but in doing so here, I beg to be understood as not in any way depreciating the project for the extension of the line of road to the Sylhet Plain. Without this extension the project would be but a half measure, and its great political and social advantages would remain undeveloped. Besides, I state the opinion of the Civil Authorities when I say, that without a cart road to Sylhet it will be impossible to keep Shillong supplied with ordinary provisions.

As I write, it is just a year since I commenced exploring the country to the south of Gowhatty, and we now have the road (with the exception of a break of about ten miles) open for ponies or laden mules. Those ten miles will, I expect, be completed by the time the Report is in the hands of the Lieutenant-Governor. There are narrow places where little could be done without blasting, and although long since applied for, neither tools nor powder have been sent from Calcutta.

We have suffered from the want of Officers and subordinates generally, while the want of labor has, of course, been a great source of trouble and anxiety. It is not solely the result of a paucity of inhabitants in the country; a good deal is due to the want of Assistants and fit subordinates, because had they been available, work could have been commenced at many different places, drawing labor from the neighbourhood which could not be induced to move to more distant parts of the line.

The entire outlay up to the present date has been Rs. 14,655, and upwards of seventy miles are open to a minimum of 5 feet in width. This sum includes all expenses in surveying and laying out the first trial lines; in carefully surveying for Estimates thirty miles of finished bridle road; in a mile and a half of very heavy earthwork in the Gowhatty Plain, where the road passes through inundated ground; in building temporary timber and bamboo bridges over every stream; in clearing jungle for 50 feet on each side of road for twenty-five miles; in building one Inspection Bungalow and commencing another; in building numerous sheds for tools and hutting coolies; and in carrying out provisions for them, and establishments generally.

Upon the whole road the average cost has been close upon Rs. 200 per mile, which includes balances in hands of disbursers and contractors.

Considerable interruption to progress has been occasioned by the necessity of sending out from Gowhatty all requisite stores, provisions, and tools; carriage for such draws a number of laborers from road work, and disgusts many more who object to be made porters of. I am now in treaty for the purchase of some mules, which will, I trust, be a source of relief to all parties.

We are establishing shops for grain near all the Inspection Bungalows, so that, I trust, ere long the road may be travelled without inconvenience or hardship.

I will now describe the line I have selected for the descent from Shillong to the Sylhet Plain, which, for reasons stated, differs somewhat from the line I examined in 1862. The highest point reached by the road at Shillong is by aneroid 6,088 feet above sea level. The Sylhet Plain is by the same instrument 52 feet. The base required for such descent at a continued gradient of 3 feet in 100 is thirty-six miles nearly. The intervening valley of the Bogopanee and the necessity of keeping as near as possible to the watershed line, to avoid a mass of difficulties which the well-known precipitous walls lining the southern face of the Cossyah range presents, obliged me to increase this base to fifty-three miles. But this is no drawback to the excellence of the line, because an unbroken ascent of 3 feet in a 100 for so great a distance would have been very severe upon draught cattle, and the selected line in no place proceeds very much out of its true direction.

The difficulty was to find a base of sufficient length which did not run us into the great natural bastions of sandstone above-mentioned, and which would not necessitate zig-zags, those most objectionable make-shifts for avoiding difficulties in hill roads. This was the objection I found to the line explored in 1862, when I came to lay it out.

I first of all examined two lines running through Cherra Poonjee, (which station I should have liked to have brought on to the line of road,) one to the westward by Chelah, the other, taking the line projected by Lieutenant Yule (now Colonel Yule, C.B.) in 1842, for the incline from the coal mines to the plain. Both I found led through very difficult ground, and would have entailed many zig-zags. Besides, Cherra stands immediately overlooking the plains at a height of 4,400 feet above them; such a difference of level would have required a base of at least twenty-two miles, whereas the distance by footpath is not above eight. This would not only have been a highly unpopular feature in the road, but would in reality have considerably increased the distance from Shillong to the plains, as the country between Shillong and Cherra undulates too steeply for a cart road upon the line of the present path, and this would have necessitated several inclines quite out of the true direction, thereby considerably lengthening the distance beyond what it is at present.

I then tried the line which I explored in 1862 through Lailankhote, descending from the gorge by the stream which flows southward towards Ponduah, but this led through such ground that for miles I could not obtain even footing. To explore the line for a hill road when the glens and ridges are covered with jungle, and to lay it out at a restricted gradient, are two such different operations that it is almost impossible to estimate by mere exploration either distances or difficulties.

I lastly tried a line through Lailankhote down the long spur passing Nonkredem, the residence of the Rajah of Khyrim, and abutting on the Sylhet Plain at Lukhet. Here I found a possible base line through a contry generally favorable (with the exception of four miles near Nonkredem), reaching the plain within twenty miles of the station of Sylhet.

In my letter above quoted I suggested that the southern terminus of the road should be at Chattuck, because that was the highest point on the Soormah that steamers could reach at all seasons of the year; but it has since been pointed out to me that Chattuck is no base from which supplies for Shillong could be drawn, and that unless easy communication is established with Sylhet, there will be great risk of the troops and residents at Shillong being hard-pressed for provisions. Again, it has occurred to me that, as Shillong is looked to as the great sanatarium for the hundreds of European Planters who will ere long overspread Cachar and Sylhet, it is but right, provided there is no fatal objection, that the southern approach to it should be from a central point, such as the town of Sylhet.

In my letter of the 9th December 1862, I was led into error as to the probable distance from Gowhatty to Chattuck, which I stated as about 104 miles. The almost impenetrable mass of jungle which covered a portion of the hills between the Cossyah range and Gowhatty prevented my seeing much of the sinuosity of their contour, and my endeavors to reduce the general gradient to a rate not exceeding 1 in 30 have considerably added to the distance, which will now be, from Gowhatty to Sylhet, 154 miles. The distance by the old mountain road *viâ* Cherra Poonjee is 142 miles. Considering that the first is to be a cart road with no gradient exceeding 1 in 25, and the second was laid out without reforence to gradients at all, except that at which a pony could climb, the result is more favorable than that ordinarily obtained in hill roads.

I will now examine, in detail, the line adopted from Shillong to Sylhet, of which about four miles in the valley of the Bogapanee is open to 18 feet in width, and the rest only laid out.

Leaving the western shoulder of Shillong at 6,088 feet, the descent of 600 feet to the torrent of the Bogapanee is effected at a gradient of 1 foot in 33 for four miles, and nearly level for two. The hills are bare and covered with short grass. The geological formation presents few difficulties. This is the chief iron region of the Cossyah Hills, and large quantities are continually being taken to Lukhet to barter for grain and the produce of the plains. The projected road will assist this traffic greatly.

The erection of a stone bridge over the Bogapanee with timber platform was commenced last year, but a very great rise in the river swept away the centre pier before it was half built up, and a fresh project, avoiding any intermediate pier, is now under preparation. Four miles further down this river, an iron suspension bridge was built about 1844, but was swept away by an extraordinary rise in the river six years afterwards. I believe that an entirely stone bridge of one opening of 90 feet span will prove the best structure for this very troublesome torrent.

After a mile and a half of ascent through huge boulders of granite the road reaches Lailankhote, where it crosses the Cherra Poonjee and Jowai road. The ascent is easy, and with proper blasting tools, the formation of the roadway will not be difficult. From the Lailankhote plateau commences the steady descent to the Sylhet Plain, unbroken, except by a few level portions, and it is between Lailankhote and Nonkredem where the only real difficulties of the line are met with. The hill sides are there very steep, and the rock line near the surface. It is, according to Oldham, of the metamorphic series, and is decidedly difficult to work.

The first difficulties are caused by a sudden break or wall in the spur of 460 feet in depth. This obliges us to cut the road out of the steep hill side facing the east, which is exceedingly rocky and precipitious. There is no other available line, and so we must face it. After reaching the bottom of this wall at an obligatory point called Roloo, we skirt a peculiarly isolated hill and pass on the watershed line, following it to Nonkredem. In several places it is nothing but rock forming narrow sharp ridges, at present broad enough only for a very bad mountain path. These sharp ridges will have to be cut down until a sufficiency of width is obtained for the road. As stated in my letter above quoted, it is scarcely possible to have all this rock excavation effected without the assistance of a Company of Sappers, or at least a body of men accustomed to blasting operations. We have taught a few men here and there; but I can testify, from long experience in such operations, that a mass of excavation in rock can only be successfully accomplished by the concentration of a considerable force worked in a systematic manner.

After passing Nonkredem we return to the sandstone formation, affording easy ground for a hill road passing over grass slopes broken here and there with oak woods. On the opposite hill, Cherra Poonjee can be easily seen, but between it and the line lies a tremendous chasm, eight miles in width and 4,000 feet in depth.

The same easy ground extends the whole way down till within 1,000 feet above the Sylhet Plains. Occasionally rocks are met with, but no extensive cliffs. The hill sides are generally pretty clear of jungle, and nothing could be more favorable for a line of hill road. At Tunginath, 4,400 feet above the sea level, the coal seams described by Mr. Oldham* are passed. The distance to them by road from the plains will be probably twenty-five miles.

At 1,000 feet above the plains commence dense plantations of areca, jack, and orange trees, for which the south face of the Cossyah and Jynteah Hills is famous. They grow on very little depth of soil and over rough rocky ground. The road will be expensive throughout these five miles of descent, but not more than ordinarily so in hill road work. There will be a good deal to pay for compensation for damage done to the plantations, probably about Rs. 3,000 per mile, or Rs. 15,000 in all.

It may be well here, where my description of the hill portion of the road ceases, to state what my opinions are now as to the mileage cost of a 24 feet road across from plain to plain. Assuming as the rates for excavation, Rs. 5 per 1,000 in soil; Rs. 8 in stony ground, reducible with pick-axe and crowbar; Rs. 15 in rock and slate, where frequent blasting will be necessary; I estimate that there will be—

56	miles of the first.		
67	„	„	second.
7	„	„	third.

The section of the first class will give about 2,64,000 cubic feet per mile. The section of the second about 6,33,000 per mile. The section of the third about 12,67,000 per mile. From this we have—

	Number of miles.		Cubic feet per mile.		Rate per 1,000.			Cost.
First class, ...	56	×	2,64,000	×	Rs. 5	=	Rs.	73,920
Second class, ..	67	×	6,33,000	×	„ 8	=	„	3,39,288
Third class, ...	7	×	12,67,000	×	„ 15	=	„	1,15,000
400 masonry culverts, at Rs. 5,000 each						=	„	2,00,000
(Stone everywhere procurable.)								
750 running feet of stone and iron bridge, at 120 per foot,							„	90,000
Probable cost of road within the hills, ...							Rs.	8,18,208
To this has to be added twenty miles of road in Sylhet Plain, at Rs. 4,000 per mile, ...							„	80,000
And 700 feet of masonry and iron bridges, provided the Peine and Gwine rivers are bridged, at Rs. 120 per running foot,							„	84,000
Probable total cost of road, ...							Rs.	9,82,208

or about Rs. 6,000 per mile.

* See Oldham's Geology of Khassia Hills, p. 66.

About one-half the road may hereafter require to be metalled.

I have only now to describe the portion of the line in the Sylhet Plain. It is not generally more than 50 feet above the level of the sea, and is consequently liable to inundation from the backing up of the rivers during the rainy season. This is more especially the case immediately under the hills, where the elevation is still less than on the banks of the large rivers that intersect the valley, the Soormah and Koosheearah. These, by the deposit of silt are being gradually raised above the normal level.

In any case, then, a road communicating between the hills and any town on these rivers, must pass through a certain portion of low country. The direct line from Nya Haut, where the Shillong Road will reach the plain, to Sylhet, will pass through about four miles of inundated country on either side of the Peine river. After doing so, it reaches a highly cultivated rice country passing near Durgam and Augajoor to the Salookee Ghaut on the Gwine or Ghinga Khall. From the Ghaut a very heavy bunded road exists to Sylhet, six and a half miles distant. It is also bridged, but from the employment of bad material the bridges are falling into decay. I propose having both the road and bridges put into better order. They have not hitherto been under charge of the Department of Public Works. The Peine and Gwine rivers will each require bridges of 300 feet in length, divided into bays of 60 feet. Wrought-iron girders upon screw piles will be most suitable.

In concluding this Report, I may state that from what I now know of the Cossyahs, I believe that this great work might be constructed within three years. Bringing into easy communication Assam and Sylhet, whilst at the same time it opens out a sanatarium for each, and extends the area of rich culturable land to the European settler, it affords the best security against future Jynteah outbreaks, and appears in all its bearings to be a most desirable undertaking.

D. B.

No. XCVIII.

THE "COMPTAGE AMBULANT."

Adapted from a Report made to the French Government, and given in the Annales des Ponts et Chaussées for 1864.

The Comptage Ambulant, the invention of a French Engineer,* enables an observer travelling along a road and noting the number of vehicles and horses he meets, and the direction in which they travel, to determine the mean traffic on any portion of that road.

The principal advantages gained by using this method are:—

1. That instead of getting the traffic at one particular spot, the mean traffic on any section of the road may be found.

2. The returns can be readily made by the overseers in charge of the road, with very little extra trouble to themselves, and at no additional expense to the State; and as easily checked by the Executive Engineer or his Assistant, on their tours of inspection.

By its use the inventor was able to discover some very serious mistakes in the existing returns, and on careful examination these mistakes were found to be real.

Encouraged by these results, the French Government allowed a sum of £85 for the verification and development of the plan, and repeated trials showed that the Comptage Ambulant was found to agree very closely with returns made by observers at fixed stations.

THEORY.—Let C be the mean traffic or number of horses passing over a portion of the road of any length.

U = mean velocity of the carriages travelling on it,

V = velocity of observer.

Then when the observer and carriage travel in opposite directions, the velocity with which they approach each other, is $U + V$, and when the carriage and observer travel in the same direction $U - V$ or $V - U$, according as U is $>$ or $<$ V.

Now, the number of carriages met, will be proportional to their relative velocities; for by relative velocity, is meant the distance by which the observer and carriage approach each other in a unit of time: consequently, as the relative velocity is greater, the sooner will they meet and the greater number of carriages will be met.

Suppose the traffic to be the same up and down the road, it follows that if the observer were to become stationary at that part of the road where the traffic is the mean traffic, the relative velocity would be $= U$, and V would $= 0$. Again, if the velocity of the observer is V, the relative velocity of carriages going in an opposite direction is $U + V$, as we have seen.

Call O the number of carriages met travelling in an opposite direction,

$$\text{Then } \frac{C}{2} : V :: O : U + V.$$

Suppose $U > V$ and let M = number of carriages going in same direction as observer, then—

$$\frac{C}{2} : V :: M : U - V.$$

Hence,

$$O = \frac{C}{2}\left(\frac{U + V}{V}\right) \text{ and } M = \frac{C}{2}\left(\frac{U - V}{V}\right)$$

Add these two equations, and it will be found that $C = M + O$.

If $U < V$, then $O = \frac{C}{2} \times \frac{U + V}{V}$ and $M = \frac{C}{2}\left(\frac{V - U}{V}\right)$

$$\therefore\ C = O - M.$$

In the general case, when the carriages travel with different velocities, some faster and some slower than the observer,—Let O', M' be the number of vehicles going faster than the observer and met by him, going respectively in each direction, and call the traffic for this description of vehicle C'; also let O'', M'', C'' represent the same quantities for carriages going slower than the observer.

From what has been stated above, it will at once be understood that—

$$C' = O' + M' \text{ and } C'' = O'' - M''.$$

Adding these quantities, and remembering that $C' + C'' = C$, and $O' + O'' = O$.

It results that $C = O + M' - M''$.

From this general equation the principle is obtained,—*That when the traffic is the same up and down the road, it is equal to the number of carts met by the observer going in his opposite direction, added to the number he passes going in the same direction, and diminished by the number of carts going in the same direction which pass him.*

This formula is more exact as V decreases and U increases, and when the difference of the traffic from both directions is least.

When this difference exists, this formula will not give the exact amount of traffic; but to obviate this difficulty, the observations should be taken in each direction, both going and coming, and the mean of these results taken as the true average traffic.

When C has been thus obtained, it must be divided by the time the observation took; this gives the traffic per hour, C_1. This must be divided by the horary co-efficient, or a number which expresses the ratio of the traffic during a certain hour of the day to the whole daily traffic, C_2.

This must again be multiplied by a daily co-efficient, which takes into account the inequalities due to the variations of traffic on different days of the week, and the true average daily traffic, C_3, will be obtained.

Application.—The road should be divided into sections of from 1½ miles to 2½ miles each, and stations should be always placed where the traffic varies suddenly, as at branch roads, road-side towns, &c. The Comptage Ambulant has this advantage, that unlike the stationary system, its accuracy is not materially affected by the length of the sections into which the road is divided. It merely affects the amount of detail which may be considered necessary.

At the top of his note-book, the observer writes the date and the day of the week. Whenever a station is passed the hour and minute is noted.

If from any cause he is obliged to stop for a time, he writes "interrupted at A. M., resumed at P. M."

Whenever a carriage is met going in an *opposite* direction, he notes it as O, 2 O, 3 O, &c., according as it is drawn by 1, 2, or more horses. In the same way carriages passed going in the *same* direction, are described as

M′, 2 M′, as the case may be. Carriages passing the observer, are entered as M″, 3 M″, &c.

Specimen Note-book.

Imperial Road, No. 30. Saturday, 14th April, 1865.

Overseer, ...

Passed cross road, No. 44, at 6-34 A. M.

O, 2 O, 5 O, M′, 5 O, O, 5 M′, 4 O, 5 O, 5 M″, O, 4 O, 5 O, 5 O, O, O, 2 O.

Passed cross road, No. 24, at 7-57.

O = 42, M′ = 6. M″ = 5. C = 42 + 6 − 5 = 43. Time, 83′.

$$\frac{43 \times 60}{83} = 31{\cdot}1 = C_1.$$

$$C_2 = \frac{31{\cdot}1}{{\cdot}06} = 518 \text{ horses}; \; 518 \times 0{\cdot}7 = 363 \text{ horses} = C_3.$$

3 M″, M′, 2 M′, O, 5 O, 4 O, O, O, 2 O, O, 4 M″, 4 O, O, O, 4 O, 5 O, 5 O, 2 O, M′, M′.

Passed 3rd station, at cross road, No. 27, at 9-22. Time, 85′.

$$C_1 = 24{\cdot}7. \quad C_3 = 353 \text{ horses}.$$

The horary and daily co-efficients (in the present case ·06 and 0·7) will be afterwards given for the South of France, and the means by which they were calculated, described.

The accompanying diagrams show the result of a comparison made with returns obtained by the Comptage Ambulant, and those made by stationary observers.

The abscissæ represent the length of the different sections and are drawn to a scale of ·01 metre to the kilometre; the ordinates, the number of horses, drawn to a scale of ·01 metre per 100 horses.

Stations were established at branch roads and intermediate posts were fixed where the distance exceeded half a mile.

Altogether there were 54 stations, but as each observer at branch roads kept two returns, one for the traffic before, and the other for that after, passing the branch; the number of stations practically amounted to 75.

For the Comptage Ambulant the same stations were naturally retained. At four principal stations only were the returns taken during the whole of the 24 hours, and the pages of the note-books were divided into hours by lines drawn horizontally across the page.

At the 50 other secondary stations, only seven countings of ten hours each, from 6 A. M. to 8 P. M., were taken.

An example will best explain the mode adopted in determining the traffic at intermediate stations.

Seven observations made on the Imperial Road, No. 44, at the 56th kilometre, gave a total of 679 horses during the seven days. On the same days at the same hours, 756 horses were counted at Travecy (Fig. 3). From this it was concluded that the traffic at these two stations was in the ratio of 679 to 756. But the traffic at Travecy had been found to be 156·5 horses; hence, that at the 56th kilometre was taken at $156{\cdot}5 \times \frac{679}{756} = 141$ horses.

It has already been observed that the pages of the note-books were ruled across the page by horizontal lines into hours, and it will be hardly necessary to detail the manner in which the daily and horary co-efficients were calculated.

HOURLY CO-EFFICIENTS.

Hours of the day.	Winter—November, December, January, February, and March.	Spring and Autumn—April, May and October.	Summer—June, July, August, September.
From midnight to 5 A. M.,	0·02	0·04	0·04
5 to 6 A. M., ...	0·03	0·04	0·04
6 „ 7 „ „ ...	0·03	0·05	0·06
7 „ 8 „ „ ...	0·05	0·06	0·07
8 „ 9 „ „ ...	0·07	0·07	0·07
9 „ 10 „ „ ...	0 09	0·07	0·07
10 „ 11 „ „ ...	0·09	0·08	0·07
11 „ 12 „ „ ...	0·07	0·06	0·05
12 „ 1 P. M., ...	0·06	0·04	0·04
1 „ 2 „ „ ...	0·07	0·05	0·04
2 „ 3 „ „ ...	0·07	0·06	0·06
3 „ 4 „ „ ...	0·07	0 07	0·06
4 „ 5 „ „ ...	0·08	0·08	0·07
5 „ 6 „ „ ...	0·06	0·07	0·07
6 „ 7 „ „ ...	0·05	0·06	0·07
7 „ 8 „ „ ...	0·04	0·05	0·06
8 to midnight, ...	0·05	0·05	0·06
Total,... ...	1·00	1·00	1·00

It will be observed that the traffic is most on Saturday, and least on Sunday; that it is greatest between 9 and 10 A. M. and 4 to 5 P. M., and attains a minimum at noon, the coachmen's dinner hour.

In this paper a very cheap, simple, and sufficiently accurate means of determining the traffic on any part of a road has been pointed out, which might easily be introduced into road divisions in this country.

It would first be necessary to make observations at fixed stations during a whole year in order to obtain the hourly and daily co-efficients applicable to the district. Afterwards, it would be sufficient to require two returns from each Overseer in charge of a section, and one from the Assistant Engineer in charge of the sub-division, monthly.

Probably there are few districts in India where the traffic is sufficiently developed or settled, to secure at first such uniformly consistent results as those given with this paper.

The principle of comparing the wear and tear, *i. e.*, the amount of money spent on the repairs of a road, with the traffic passing over it, is a most important one, which has hitherto not been sufficiently studied and cannot be commenced too soon.

I would suggest that accompanying his annual road repair estimate, every Executive Engineer should send in a general report, in the form given on the next page, showing the quantity of material and labor expended in repairing and maintaining each mile during the preceding year—the traffic on it—the wear of metal—and the character of the metal employed.

The return might be illustrated by plotting the lines of traffic in a similar way to the diagram given with this paper.

In this way valuable statistics would be acquired, which when properly generalised, might yield important principles.

ARTHUR J. HUGHES.

[*Some of the columns in the annexed Table might perhaps be simplified. On the other hand, more details of traffic would be wanted, showing what animals are employed in draught and what in carriage. The damage done by wheels is far greater than that caused by the hoofs of animals; but in France, and other civilized countries, where the carrying traffic forms an insignificant item compared with that drawn on wheels, no distinction is probably made.*—ED.]

YEARLY REPORT, SHOWING COST OF MAINTAINING, DURING THE YEAR 1865-66, THE ______________ ROAD.

Year.	Cost of labor on repairs to earthen sides and slopes.	ANNUAL AND PETTY REPAIRS.				Description of kunkur.	Resistance to crushing, per square inch.	Average thickness of metal on 1st November last.	Added since.	Present thickness.	Wear in cubic feet per mile.	AVERAGE DAILY TRAFFIC.		Total.	Cost of maintenance per mile per annum, for a traffic of 100,000 bullocks and horses per diem.	Wear of metal in cubic feet per mile per annum for a traffic of 100,000 bullocks and horses per diem.
		Total cubic feet of kunkur expended.	Total cost of road metal expended.	Total cost of labor expended.	Total cost of labor and material.							Bullocks.	Horses.			
1856.																
1857.																
1858.																

' Or other metalling.

No. C.

NOTES ON LEVELLING.

It may seem rather an obvious remark that Engineering plans and sections should show clearly the datum planes to which the levels are referred, but experience has shown the writer that this point is often much overlooked in this country; and the trouble and loss of time which he has seen caused from want of system and method, has induced him to draw up some notes, based on rather extensive experience at home and in India, with the view of pressing this matter on the attention of his brother Engineers.

The following instances, which have occurred in the writer's own experience, will illustrate what is meant.

Case A.—A large military cantonment had been carefully levelled for purposes of drainage. The levels were shown in figures on the plan, referred to a datum 100 feet above the parapet of a bridge, "marked X," in the staff lines. The original plan was not forthcoming; in the copy the draftsman had omitted the distinguishing letter against the bridge in question. Not a single other bench-mark was shown on the plan; and, consequently, the levels could not be connected with any subsequent ones, nor could they be used for setting out works.

Case B.—A large bridge was being built over a river, the course of which had been surveyed several years before, and a number of cross sections taken, which were recorded in figures on a plan.

Before the bridge was begun, a longitudinal section of the bed, and a cross section at site of bridge were taken by another officer, who, instead of connecting his levels with the previous ones, referred them to a datum

"50′ below the point B on plan." Upon turning to the plan, a letter B appeared certainly, but there was nothing to show *what* B meant. It turned out on inquiry that B had been a bench-mark on the centre line pillar, which had been pulled down by the Overseer in charge soon after the works were commenced, and there remained no means of comparing the levels of the work executed with those designed.

Case C.—It was required to collect information as to the levels of a tract of country, some 20 miles by 15, for certain hydraulic works. The tract included a part of the Grand Trunk Road, several large rivers, some drainage works, and a large cantonment. The writer had to wade through a huge mass of plans and sections, taken by a dozen different officers during a period of twenty years, and representing a vast amount of toil and trouble. The information, if it could only have been reduced to an available form, would have been most extensive and valuable. But it was found not only that each officer had worked independently of others with different scales, and different datum planes; not only that some had taken a datum in the air above and some in the earth beneath; but that in the vast majority of instances, either no datum at all was given or it was so vaguely described, that after the lapse of years identification was impossible, and the levels could not be reduced to a common datum.

Of the whole mass, but two sets of plans were found to be practically useful, and even these were most defective. One of them extended over almost the whole tract of country, but no bench-marks were given except along the Grand Trunk Road, though some of the sections extended 20 miles away from it. So in order to connect any fresh levels with the old ones, it might be necessary to run 20 miles merely to pick up the bench-mark.

It would be easy to avoid all this painful loss of labor if Superintending and Executive Engineers would only adhere to a fixed system. Let a few simple rules be adopted, any deviation from which shall require satisfactory reasons to be furnished by Executive Engineers.

The most convenient way of showing the general levels of a district, is to write the height of each point above datum where an observation has been taken, on the plan itself. Every bench-mark should be shown on the plan, and its reduced level entered in figures with the description of the locality, if not too long. Important bench-marks should be described in detail in the margin, with a sketch if possible, so that ten years afterwards any stranger can go straight to the spot. Bench-marks should be taken profusely, at every half mile at least, and near rivers, roads, &c., much oftener.

As far as possible, a uniform scale should be adopted, so that copying and reducing from one scale to another may be got rid of. For plans of cantonments, drainage works, and general purposes, 400 feet to the inch horizontal, and 20 feet vertical, are the most convenient scales. Each Superintending Engineer should insist upon these, or some other uniform scales, being adopted throughout his circle. And all over India, levels ought to be referred to one and the same datum, the Trigonometrical one. The Surveyor General has published the heights of bench-marks over a large part of India, and each Executive Engineer should have a permanent bench-mark connected with the nearest trigonometrical one, to which all his levels should be referred. As a datum plane 700 or 800 feet below the surface would be inconvenient, there is no objection to assuming one 500 or any even number of hundreds above the sea level, so long as it can be at once compared with the standard.

Bench-marks require some judgment to be exercised in their selection. The place should be one that can be easily found and recognized, and the exact position should be invariably marked with the broad arrow and bar across the points, adopted by the Ordnance Survey. Permanency should be more attended to: not one bench-mark in ten, in the writer's experience, fulfils all the required conditions. The best place of all, because least likely to be disturbed, is the face of an unplastered brick wall; the broad arrow is an indelible mark, and the bar is just as well defined a place to hold the staff on as a door step or plinth. A door step, and especially the centre of it, though used by the G. T. Survey, is not a good mark; the centre of the step gets worn down and has to be renewed, especially in this country, where it is often of brick; and thus the exact level is lost.

The Ordnance bench-marks in London are generally on the face of a wall; the writer has always found them easily, in fact they catch the eye at once if well and deeply cut.

It is to be regretted that even in quite recent projects, such as the Sutlej Canal, the Trigonometrical datum has not been adopted. Superintending and Chief Engineers can easily require all sections submitted to them to be referred to this datum, and it is to be hoped that this will soon be done.

It would be well worth while to appoint an officer to each circle to go through all the data in each office, revise and extract the useful part, connecting different series of data where necessary, and reducing them to a uniform system. The saving of useless labor in preparing future projects would be very great, but Executive Engineers are too over-worked already to undertake anything of the kind themselves. The general knowledge which an officer so employed would gain of all the Engineering data throughout the circle, and of the relations between different divisions, would render him a most useful assistant to the Superintending Engineer, when his special work was done.

K. C. L.

Addendum by Editor.

In continuation of the above, the following hints may be found useful:—

When series of levels are taken over a tract of country, the plan and sections of such levels should correspond exactly. If the scale is not too small, the measured distances between stations should be shown in *both;* the numbers of the stations, as shown in the field-book, being given at every 5th station on the plan and section, with the reduced levels written on the plan in red ink. The situations of bench-marks should be shown accurately on the plan, and the reduced levels be written, clearly showing to what exact spot the numbers refer to. Wherever the scale admits of it, the information given on the plan should be so full and complete, that the sections can at any time be drawn out from it alone; and, if the bearing of the different lines be written on the section, the plan may, conversely, be laid down from the sections alone.

Where a line of levels crosses a water-course, the reduced level of the bed of such water-course should be shown—that of the water surface (the date of observation being given)—of highest and ordinary flood mark, if discernible—and that of the top of the bank; and all these reduced levels should be shown on the plan.

Most of these injunctions will appear obvious, but the fact is, there is not one plan or sheet of sections in twenty, where such information is given.

A word on Field-books. Many forms are in use, and an experienced leveller will generally prefer his own. As a help to the inexperienced, three forms are given of such as are now printed at this College, which have been found useful.

FORMS OF LEVELLING FIELD BOOKS.

No. 1. Roorkee Pattern.

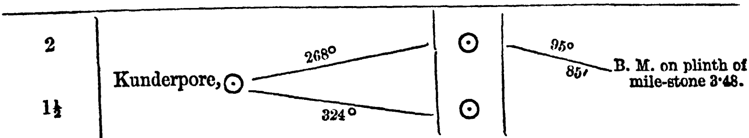
Stations.	Back.	Forward.	Distance.	Bearing.	Rise.	Fall.	Reduced Level.	Remarks.
							451·42	R. L. of Station 1. (G. T. S.)
1—2	4·56	5·34	600	187°		0·78	450·64	
2—*a*	6·18	(3·48)	85	95°	2·70		(453·34)	*a* is a B. M. on plinth of mile-stone.
2—3		5·54	600	187°	0·64		451·28	

Reduced levels always refer to forward station.

No. 2. Canal Pattern.

No. of back station.	BACK.		Dist., fr. Inst., to each station.	FORE.		Difference.		Reduced Level, of back station.
	Read.	Bear.		Bear.	Read.	Rise.	Fall.	
1	4·56	7°	300	187°	5·34		0·78	451·42 R. L. of G. T. S.
2	6·18	7°	300	187	5·54	0·64		451·28
3								

Opposite Page for Survey.



Station 1½ is between 1 and 2, where the Instrument is set up.

No. 3. English Pattern.

Back Sight.	Intermediate Sight.	Fore Sight.	Reduced Level.	Distance.	Remarks.
5·24			325·40	0	R. L. of G. T. S.
	4·72		325·92	100	
	4·34		326·30	200	
	4·87		325·77	300	
6·24		5·18	325·46	400	

The Station may be referred to by the numbers in the distance columns, the chain line being continuous throughout.

No. 1, the Roorkee pattern, is perhaps the most useful for flying levels, as where cross sections are required of a line of country for a Road or Canal; the form of keeping it is shown, the rings round some of the levels showing that they are out of the main circuit.

No. 2, or the Canal pattern, was used on the Sutlej Canal Project, and has been adopted generally for the Irrigation Department in these provinces.

No. 3, the English pattern, is the best, perhaps, in actually laying out work, and where levels are required at every chain apart.

Nos. 1 and 2, are the best where a survey is required together with the levels. The book may be interleaved with blank pages, on which the usual chain line may be drawn marking the stations and the off-sets or cross bearings; opposite pages referring to the same stations. Many Surveyors, however, prefer two field-books, one working with compass and chain, while the other takes the levels only, both however, using the same stations.

Whenever possible the Surveyor should plot his own field work, but where time is an object, field-books can be sent in and plotted in the office while the field work continues, and this cannot be done unless Field-books are kept with clearness and accuracy. A Surveyor who *copies* any work into his Field-book, or who makes a fair copy of any portion thereof, should meet with no mercy.

K. C. L. must remember that it is only quite lately that the G. T. Survey levels have been made available as points of reference. They will no doubt be used as suggested, as fast as they are taken and published. The following description of the *modus operandi* by the officer in charge of the work, Lieut. Trotter, R. E., will show the extreme care that has been taken to ensure the accuracy of these important levels. Some further account of the operations may be given in a future number.

"The Instruments employed are standard levels, by Messrs. Troughton and Simms, of 20-inch focal length, and powers averaging 42—very superior to ordinary levelling instruments. The levels are fitted with finely graduated scales, and have their runs determined by a series of observations on the vertical circle of a large theodolite or astronomical instrument. From the mean values of 'run' tables are constructed for use in the field, showing the corrections for dislevelment, which are applied to every observation.

"As this necessitates a certain amount of computation on the ground, a trained native recorder accompanies each observer; thus dividing the labor, and enabling the surveyor to concentrate his attention on the actual manipulation of, and observations with, the instrument.

"To guide in obtaining a true perpendicular, the staves are supplied with plummets let into the sides and visible through glass doors. Swivels are fixed to the tops of the staves for four guy-ropes, by means of which the are adjusted and kept steady when once properly fixed. Whenever the staff is set up, a wooden peg is previously driven into the ground—into the head of this peg is driven a convex brass brad, which presents a smooth surface on which the staff rests, and rotates freely.

"To prevent the possibility of errors in reading the staves escaping detection, the latter are graduated on both sides, one side having a white ground and black divisions (feet, tenths, and hundredths) numbered from 0·00 foot to 10·00 feet, the reverse side having a black ground with white divisions numbered from 5·55 feet to 15·55 feet. By means of this double graduation, two entirely independent values of difference of level are obtained at each station where the instrument is set up. The staves are read off to the third place of decimals of a foot, and should the difference between the two values obtained, after the correction for dislevelment has been applied, exceed ·006 or $\frac{6}{1000}$ of a foot, the invariable rule is to repeat the observation. Should the day be unfavorable, observations have sometimes to be repeated as often as three or four times, the mean of all these observations being taken as the true value.

"The instrument is invariably put midway between the back and forward staves, the distance (always measured with a chain) varying during the day from three or four (66 feet) chains the maximum distance at which satisfactory observations can be made over bad ground in the middle of a hot day, to ten or twelve chains, at which distance the divisions on the staves are very clearly visible on a fine clear morning or evening.

"This rule of equal distances eliminates all errors of adjustment, also the effects of the Earth's curvature, and all constant refraction.

"Once or more during each field season, the staves are compared with a 10-foot portable standard iron bar, and any error in the length of the staves is duly allowed for in the final computations.

"The possible dislevelment of the instrument from the heating effects of the Sun's rays, is diminished as far as possible by carefully shading it, when set up, by a large umbrella. When carried from station to station, the levels are always placed in boxes in 'doolies' covered with blankets, so that the instrument is never actually exposed to the direct rays of the sun from one year's end to another.

"In previous levelling operations, it appears from very careful comparisons, made at various times and in various countries, that there is always a tendency to cumulative error in a long line, which has never been satisfactorily accounted for. The result of this error, whatever the cause or causes may be, is in the words of Professor Whewell, 'that in proceeding with the levelling operations along a line which is really level, the further end constantly appears from the observation to be the lower end, and the amount of this depression appears to increase with the distance—hence, when we go to the end of the line, and then return to the starting point, we find the resulting elevations of the point lower than its real elevation.'

"Taking this matter into consideration, a system has been adopted in our operations of dividing the line into equal sections and leveling adjacent sections in opposite directions. This manifestly does away with the injurious effects of the above-mentioned error, and indeed of all cumulative errors of this description, for the maximum error which can creep in, in a line of, unlimited length, will be the cumulative error due to the length of a single section. By limiting the length of each section to four or five miles, we do away with the possibility of any appreciable error of the kind under consideration, entering into our results.

"Another very ingenious contrivance for eliminating errors and giving us the advantage of the 'circuit system,' has been introduced into this department, viz., that of observing forward staves first at odd stations, and back staves first at even stations. By this means 'all errors are cancelled that might occur in a constant order, such as might be caused by a uniformly rising or uniformly sinking refraction, or by a tendency in the instrument to settle on its axis one way more than another on being set up for observation.'

"On closing work at the end of a day the invariable rule is, if possible, to close on some 'paká' mark. Should this not be possible, large pegs (2 feet long or more) are driven into the ground at the last two stations, and well rammed home. These stations are both re-observed when work is resumed.

"A second observer, with a separate instrument, recorder, staves and khlassies follows, station by station, over the same ground, in rear of the first, resting his staves on the same pegs and brads that were used by his predecessor, and carefully comparing the two results. Whenever a difference exceeding ·006 of a foot appears between the results of the two observers, the observations of the second are repeated, and should the discrepancy remain, the prior observer is recalled, to remeasure that station, unless it should appear that the difference is owing to the fore staff peg having been moved between the two sets of observations, which would be at once shown up by there being a corresponding and compensating error in the results obtained at the next station.*

"As a test of the accuracy of our results, it may be stated that in bringing up independently the results obtained from the two different observers, the maximum divergence between them in the section, Calcutta to Tilliagharí (242 miles), never exceeded ·2 of a foot, the terminal difference having been ·15 foot. In the section, Tilliagharí to Patká Gerouli (346 miles), the maximum difference was ·40 of a foot, with a terminal difference of ·38 foot; and in the section, Agra to Patká Gerouli (342 miles) the terminal difference was only ·06 foot, with a maximum of ·15 foot."

* The first season's work was executed by *three* different observers, all using separate instruments, staves, &c., and following one after the other in the manner described.

No. CIII.

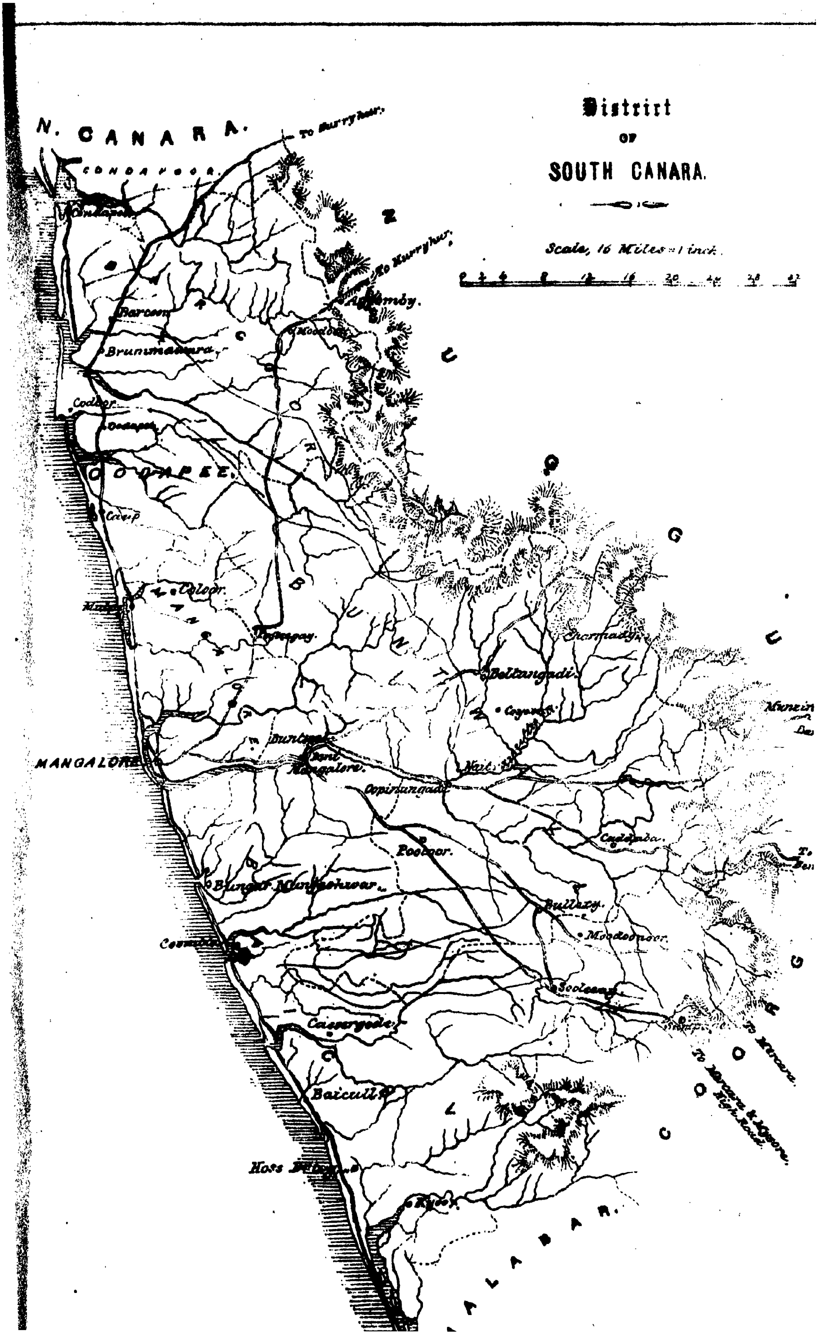
ROAD TRACING IN SOUTH CANARA.

BY AN OFFICER OF THE MADRAS ENGINEERS.

THE district of South Canara, in the Presidency of Madras, lies throughout its whole extent directly between the province of Mysore and the sea. In physical character it differs widely from North Canara, although to a certain degree it bears a resemblance to it in some of its general aspects. Stretching along the sea, from the 12° 11′ parallel to the 13° 39′ parallel of latitude, and exposed to the influence of the south-west monsoon; the climate is equally moist, the rain-fall equally heavy; but the whole of the district is situated below the Ghauts, which close it in on the east side with an amphitheatre of hills. It is bounded on the north by Condapoor, a *taluq* (revenue division), that since 1862 has been incorporated with it, and by the Nuggur division of Mysore; on the east by the Astagram division of Mysore and Coorg; on the south by Malabar; and on the west by the ocean. The superficial area is, excluding Condapoor, about 3,680 miles, and the population is estimated at 175 souls to the square mile. The traveller entering South Canara from the north, is struck with the tameness of the prospect, and the scantier vegetation, as compared with the bold scenery and dense foliage of North Canara; and this impression does not wear off, until getting eastward in his wanderings, the frowning heights of Mysore and Coorg recall the beauties and grandeur of those left behind. The seaboard is deeply indented by numerous tidal rivers, on almost all which there is much boat traffic. Some of the streams reach far inland; and although low and full of rocks in the dry season, are for four or five months in the year capable of being navigated, with ease and profit, by strong capacious canoes, hollowed out of the trunks of trees.

Before the British occupation, there were few other facilities for a carrying trade. The roads were mere paths, very stony and steep; and where led up the face of the Ghauts, almost impassable. The face of the country has been aptly described as being like a trayful of inverted tea cups; there is scarcely a flat piece of ground to be met with in it; and over such a tract it may be imagined no carts can run; in 1838 not one wheeled conveyance was to be found in all South Canara. Although Mysore has other outlets for its produce towards the Coromandel coast, and does not export so largely as the Southern Mahratta country, the trade is considerable, and the return traffic in salt and other articles large. But as the difficulties of transit are less in this district than they were in North Canara, they did not obtrude themselves upon the notice of the district officials so promptly; it remained for war to direct attention to the communications. When the Coorg insurrection broke out in 1837, the troops quartered at Mangalore, the chief town of the district, were actually unable to penetrate the thick forest which overspread lower Coorg, now a part of Canara; nor could artillery be moved along such broken and singularly steep and tortuous ways as were then the only means of traversing the country. With a view to prosecute the war, and when brought to a close, to pacify the district, a first class Ghaut was lined out from Mercara, 3,000 feet above the sea, to the small hamlet of Sumpage at the foot, on the usual gradient for that description of pass, of 1 in 19 or 1 in 20; and a road was traced, from Sumpage to Mangalore, for a distance of 70 miles; much of it across very formidable obstacles, since for the first 30 miles from the foot of the pass the ground is very undulating and the forest thick. It is stated, that Ghaut and road combined, cost the small sum of £400 a mile when finished; but this can scarcely include all the bridging, although most probably three-fourths of it. Being a military line, it was carried out with expedition, and with the aid of an efficient staff of superintendents. The width is at least 21 feet, and the section is good; the surface is also hard, and easily kept in repair, much of it consisting of laterite gravel, or stiff gravelly clay. Indeed, it is one of the best roads in the Madras Presidency, and stands an increasing traffic with but little outlay or repairs, or some £10 per mile per annum. The Sumpage Ghaut is not within the limits of the district, but is attended to by the Mysore authorities; it is believed to be in fair order.

[illegible] celebrated for its coffee. The planters have cleared


District
of
SOUTH CANARA.
Scale, 16 Miles = 1 inch.
N. CANARA.
CONDAPOOR.
To Hurryhur.
Agoomby.
Moodbidry
Brummawara
Barcoor
Codloor.
COORG
BUNT
MANGALORE
Buntwal
Beltangadi.
Opinunqadi.
Pootoor.
Cudepaba.
Bullary.
Moodonoor.
Scoleany.
Cassergode.
Baicull.
Hoss Dirgoo
MALABAR.
To Mercara.
To Mercara & Mysore High Road.
Colloor
Camp

numerous estates in the vicinity of nearly all the Ghaut roads constructed by the Government, both in South Canara and Malabar. Many settlers have selected Mercara as their field of operations, and every year transmit their crops to Mangalore by the Sumpage lines for cleaning and shipment. The general traffic, however, of the Mysore district in the south-east showed a tendency to quit the military road leading to Mangalore, for a track conducting to the minor and nearer port of Cassergode. To accommodate it, a district road was subsequently formed and proved useful. It leaves the former some 20 miles from the foot of the pass, at a place called Jalsoor. Cassergode is a mere village; but being a salt depôt and accessible to country craft, and also closer to the Mysore frontier than Mangalore, is of some little importance. The Mercara and Mangalore road is bridged with one notable exception at the Naitravutty river near Buntwall, where a wide stream presents an obstacle not yet, after the many years of British domination, surmounted. It is crossed by means of a ferry, the boats employed on which are fastened two and two together, after the fashion of a pontoon raft. They are of the usual solid make of the district, and placed at about 9 feet apart from centre to centre. Upon their gunwales is supported a stage some 12 feet square, railed in on either side, which carts and animals ascend over a moveable inclined plane. The raft is moved by men working paddles, which they hold in their hands and wield as scoops from the stems and sterns of each of the boats. These ferry platforms, termed "jungars" in local phraseology, are so far convenient if the traffic to be accommodated is light; but when it is heavy, there is great delay at every ferry that cannot be avoided except by providing a large number of boats and extending the jetties or landing places. In the rainy season, when the river is in full flood, the inconvenience of crossing is much felt.

The sight of a first-rate road on either bank, and only a ferry boat to connect the two branches, naturally suggests the bridging of the Naitravutty at this point: and seeing the river is a quarter of a mile or more in width, the bridge if ever built, will be an imposing structure. The Naitravutty rises enormously during the monsoon, and often lays part of the road, about twelve miles out of Mangalore, under water, flowing over culverts and even bridges. A boat can sometimes sail upon the road in 4 or 5 feet depth of water for some distance, whilst thus submerged; there must, therefore, be sufficient allowance made for waterway, by whoever may have the designing of the Naitravutty bridge at Panimangalore hereafter, in order that the occurrence of one of those catastrophes, much too common on the western coast, may be prevented. Several of the bridges on this very Mercara road, are second, and even third attempts, through the deficiency of water passage at first given, and that not attributable to unskilful estimation, but to the absence along the streams of any reliable indications of highest flood marks. An iron girder bridge on Warren and Kennard's triangular lattice system, as employed upon the Bombay and Baroda railway, would suit the locality better than either a masonry or a timber bridge. The foundations of the piers would rest throughout upon solid granite rock, and the piers should be constructed of cut granite. The relief that this work would afford to the trade of Canara and Mysore would be signally great; and it is to be hoped that ere long its commencement may be arranged for. As a set-off to the cost of erection there would be the collections from a toll upon it, which could not fail, judging from present ferry receipts, to remunerate in time.

About twenty miles north of the Sumpage Ghaut, as the crow flies, is the sister Coffee Ghaut of Munzirabad. To reach it, however, from Sumpage, it is requisite to go round by Pootoor, Oopinungadi, and Goletuttu, along made roads, which are kept in tolerable condition by a maintenance grant of £5 to 10 per mile a year. Pootoor was once a detachment station, but is at present held by the police. It is a dull uninteresting spot, but useful as a retreat when fever spreads in the jungly triangle contained between the Munzirabad and Sumpage roads and the Ghaut chain. There is a good road from Pootoor northwards to the banks of the river at Oopinungadi; but the direct route from Munzirabad to Mangalore joins the Sumpage trunk road at a place called Mauny in the map. The river at Oopinungadi is 700 feet wide, and has steep and lofty banks. A girder bridge is likewise sadly needed here: its character would be similar to the one described as wanted at Panimangalore; but it would be easier and cheaper to set up. A ferry platform boat takes the carts and passengers across; and for a month or so (the end of April and May) they contrive at some little risk to wade over and thus elude the ferrymen's exactions. Nowhere in India almost is a bridge more required.

Oopinungadi is a wretched village consisting of a short street of huts, and has been stationary for several years. It is perched on an angular piece of ground at the confluence of two large rivers, and has the reputation of being infested with fever, which accounts for its not increasing in population. Thence the road to Munzirabad runs through an undulating and tolerably open country, until on proceeding along it for some eighteen miles a dense forest is entered, that lasts with few breaks up to the summit of the Ghauts. This road has not had a sufficient amount of money expended upon it, and is not in such good repair as the trunk road first noticed. Near the Ghauts especially, its surface is rough and stony, and several gradients are too steep, causing the rain to wash off the gravelling and wear deep ruts. Nor is it bridged throughout. There are, however, not a few bridges upon the line, some of stone and some of timber.

The stone chiefly used for building all over the district is Laterite. It is naturally a soft stone, and although said to harden by exposure, it is very much to be doubted if it does so to any depth below the mere exterior skin. Laterite occurs in large masses near the sea; but the beds thin out at the Ghauts; and a quarry worth the working is not easy to find in the interior. It has to be sought as a rule upon the tops of rising ground; and is seldom solid to a depth of more than three or four yards, gradually degrading into clay. This would seem confirmatory of a supposition, which has found supporters, that, laterite is a volcanic ejection and not of aqueous deposition. There are gangs of excavators who make the quarrying of laterite their peculiar business, and cut it out block by block from the stratified mass with light pickaxes. The blocks are commonly 18 inches by 9 inches by 9 inches, and in making calculations of bills of quantities, each is reckoned at half a cubic foot. The dissolute habits and the irregular attendance of this class to their work, are a constant source of annoyance. They get paid at the rate of 15 rupees per 1,000 stones at the quarry. Masons in Canara, barring the few who belong to the district and reside in it, are procured from Goa. A messenger has to be despatched with advances in June or July, and the labor reaches in October. Every mason brings with him two assistants, whose sole duty is to trim the stones with a scappling pickaxe. They understand their work; but are almost as convivial as the quarrymen in their leisure moments, if not so ready to desert. Laterite is put in most of the buildings on the western coast, from Goa to Cochin; and there is a very fine specimen of work in it at the Railway Station of Beypoor, where the stone is not plastered, and is neatly cut into quoins, *voussoirs and beadings, that will look imposing whilst they last.* In South Canara, and more particularly for bridges, this material has to be employed with caution, for there have been many failures. Water, and especially rain water, soaking into the stone softens it, occasioning the fall of arches and the sinking of piers and abutments. A strong current likewise eats into the latter, if not faced with cut granite; a precaution that has been wisely adopted in most instances. To plaster the exterior is the best preventive of softening; but it is a most unsatisfactory thing for an Engineer to have to rely upon so slight a guarantee for the success or the security of his constructions. Cut granite is too expensive for ordinary purposes, but granite rubble masonry might be, and in one instance was actually, tried for abutments and walling with good results. First rate brick earth abounds, and a few culverts on the Munzirabad road were built of bricks; but the temptation to brave the treachery of laterite for economy's sake, was too strong to be resisted apparently, for brick-making as an art has not taken root in Canara.

When bridges have not been made either of laterite or of brick, they have been wooden platforms on laterite piers, or as in one place on the Munzirabad road, near the foot of the pass, a bow string trussed girder. These timber platforms are of simple and solid construction and cheap, in consequence of all the beams being ready to hand in the adjoining forest. Compared to masonry bridges, however, they are inferior in several respects. In the open country, wet half the year and dry the other half, the wood must rot in time, whilst in the depths of the jungles, where the air is always moist, decay is rapid; and the planking of the roadway demands constant repair, and that in localities and at seasons in which it is scarcely possible to get skilled workmen collected. There is besides a risk from fire; more than one large bridge on the Munzirabad road having been burnt down, either through the carelessness of passers by, or by communication with the dry grass that in Canara is regularly consumed over a wide area in March and April. Subject to such viscissitudes, the Canara Engineer should pause before he builds any more of them; and should use brick or rubble, at all events in the interior and on the Ghauts.

The Munzirabad road undulates very frequently, and abounds in steep gradients for thirteen miles before arriving at the true foot of the Ghaut. By trying to escape a little blasting in rock here and there, several excesses in slope were originally perpetrated, but since 1863 most parts have been retraced and are in process of being widened out. The Ghaut foot is at the base of a long valley, up the north side of which the incline winds in a series of curves. In the middle of the valley, there flows a fine mountain torrent, and the valley is itself clothed with luxuriant vegetation of the darkest shades of green. There is, even in unclouded weather, a peculiar gloom about the base of this pass, shut in as it is on nearly every side by lofty hills and trees, that is remarkably striking. The Ghaut road is on a gradient of about 1 in 19, and passable for carts and carriages, and there is no zig-zag. The width is however deficient, and the drainage indifferent, because a clean section with a suitable drain on the inner side has not been given, partly perhaps to save expense. The pass is under the Mysore authorities, and it is worth their while to widen and improve it, blasting away the crags that intrude upon the limited space and providing inner drains; for the coffee estates at Munzirabad, at the top of the Ghaut, are numerous and valuable.

The Charmady Ghaut is some fifteen miles north of the Munzirabad Ghaut; but to reach it by road a much longer circuit has to be made. It was chiefly traced by a native maistry, and does him credit, but a more judicious line would have been selected by an officer of experience. The upper part of the Ghaut is almost a dead level, although running along the side of a deep and picturesque ravine; and most of the descent is within the Canara frontier, where for want of room the road is sent tumbling down the hill side, and along a short spur by a number of zig-zags. The gradient is 1 in 16. It would have been easy to have avoided many of the zig-zags by giving the line a heavier slope within the Mysore frontier, but the error is now past remedy. This Ghaut accommodates the traffic of the Nuggur division and Wastara; and by a road in fair order and partially bridged, communicates with the trunk road from Mercara, at Buntwall, a large native town about fifteen miles east of Mangalore. A branch road, unbridged, leaves the Charmady road at Beltangadi, and after a course of eight miles, ends near the base of a hill not far from 6,000 feet high. Access is gained to the summit by a bridle path, which it takes four hours to climb on foot and which is twelve miles long. This hill, known as the Kudray Mook or (Horse's Face) is a mere peak, isolated in a measure from the chain of ghauts, and towers over both the Mysore plateau and the Canara district. It is as cool and pleasant on the top as upon the Neilgherries, and the vegetation is very similar. Being only 40 miles from

Mangalore, it forms a welcome retreat in the hot weather that precedes the setting in of the monsoon; and in clear weather there is a fine view from it of vast extent. Forty miles north of the Kudray Mook is the Agoomby Ghaut, to furnish an outlet for the Nuggur division and Shemoga, and from its foot there is partially bridged communication with the ports of Mangalore, Mulpy, and Condapoor. Thirty miles further north is the Coloor Ghaut, leading to Condapoor; it is believed to be only traversable by pack bullocks, as the trace has not been widened out.

It will thus be seen that communication is comparatively easy from west to east in the South Canara district; indeed, very much has been done, wherever possible without incurring heavy expense, to open fair weather roads in all directions; but a considerable number of the minor roads need bridging; and the progress of the district in wealth and intelligence will be to a certain degree hindered until carts can be taken about at all seasons. Another great want is a good coast road, but it is one that will demand a large outlay. From Hoss Drug in the south to the neighbourhood of Cannanore, in the Malabar district, there is inland water communication; but thence up the coast, all the way to Bombay, there is nothing better than a foot-path with formidable estuaries to cross. A canal was once projected to unite the backwaters between Mangalore and Hoss Drug, but as it would have to be excavated through laterite spurs of some height, and as, moreover, there was no possibility of getting a grant at the time, the matter dropped. It is suggested that a road with iron screw pile bridges across the backwaters would be preferable, and that it should be carried right down from Sedashaghur, to unite with a first class road which already connects Cannanore with Calicut. This Malabar road encounters wide tidal rivers too, but they are all spanned with timber platforms resting on wooden piles. These bridges appear to need constant repair or renewal, and should, as soon as worn out, be replaced by iron structures. The Malabar district is one of the most flourishing in the Madras Presidency, and ought to be able to meet the cost of them by a moderate cess. As a temporary expedient, and to give immediate relief to trade, a road is being constructed from the Mercara trunk road close to Mauny, circuitously, *viâ* Vittel, Ahdoor, and Pullali, to the head of the navigation at Hoss Drug. By curving eastwards the backwaters are headed.

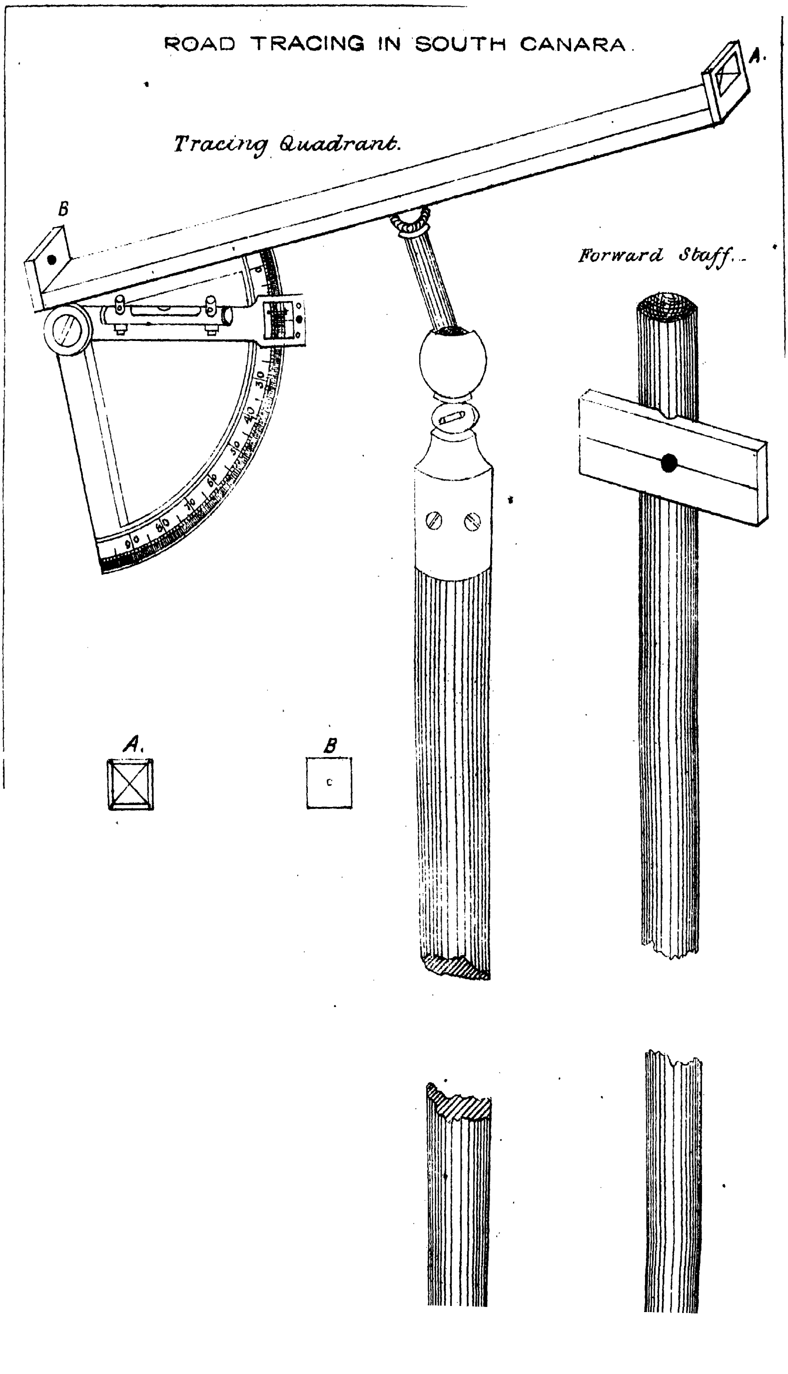
The harbour at Mangalore, has at different times drawn attention.

It consists of a wide and deep backwater, at the junction of the Naitravutty and Goorpoor rivers; having, between it and the sea, a long strip of sand, containing two breaks through which the tides ebb and flow. The distance between each of the mouths is one and a half miles; but they alter their position almost every year during the monsoon storms. The southernmost mouth is that most used by shipping, and has been for sometime remarked to be tending gradually northwards. Country craft frequent the backwater from October to May; but vessels of any size lie off in the roads. The bar at the principal mouth is most dangerous to cross during the rains, and sea communication with Mangalore may be said to be cut off for a third of the year. Under these circumstances and until the traffic of the port materially increases, the Madras Government will probably be indisposed to embark upon the extensive and costly operations that would be necessary to fix the bar and deepen it. To give even a synopsis of the investigations that many competent observers have made into the peculiarities of this harbour would itself fill a paper.

It may be gathered then from the preceding notices in detail, that, since the insurrection in Coorg, when the district had neither a road or bridge to boast of, to the present time, the Civil authorities and the Engineers connected with them, have succeeded in enabling the Mysore traffic to reach the coast; and have with a few exceptions bridged the more important lines. It is understood, however, that this was effected in the face of many obstacles, chiefly arising from scarcity of funds and of skilled superintendence. But many improvements and ameliorations are still called for. It is most desirable that the road leading from Munzirabad to Buntwall should have a liberal grant allotted to it once for all, for the correction of its gradients, the repair of the surface, and the erection of masonry bridges of first class workmanship over three or four streams now great impediments to trade. The Naitravutty also, at Oopinangadi and Buntwall, should with as little delay as possible be crossed by iron girder bridges; and no expense ought to be spared to render them solid and permanent. When these crying wants have been provided for, large sums may be expended with advantage upon masonry bridges, where required on the district roads; and upon coast roads, to link together the chief centres of population, that in South Canara are to be found on the seaboard.

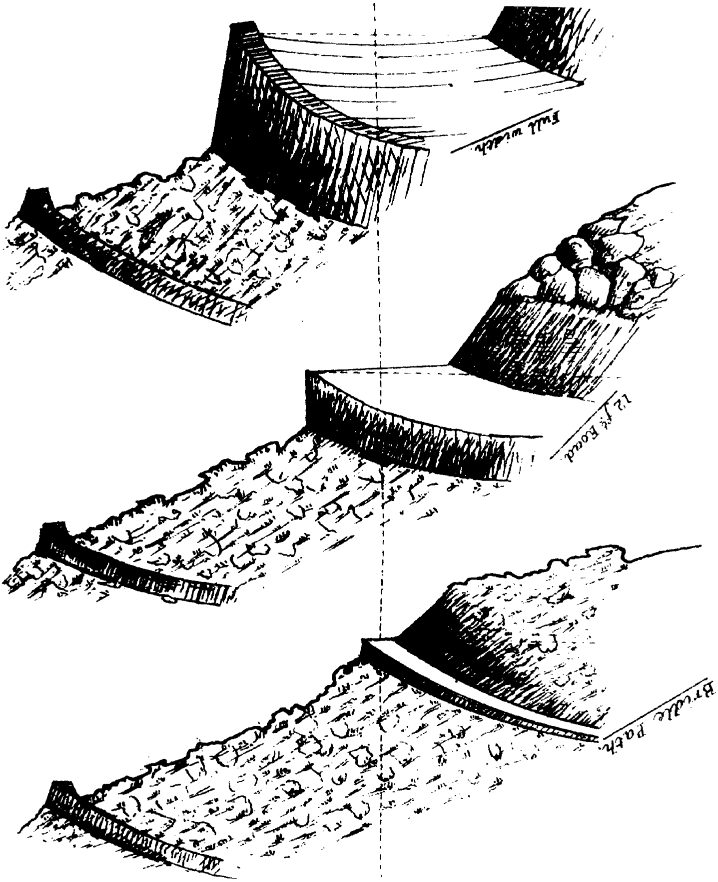
There are besides, several cross country roads to be traced to give access to villages now kept in a backward state through their isolation from the rest of the district. As they have to be formed for the most part in side cutting, it is necessary to employ the Tracing Quadrant to line them out, and the procedure is what has, in a previous, paper (*Ghaut Tracing in North Canara*, Vol. II., p. 321) been described. The tracer holds the instrument in his hand, having adjusted the armature by the scale and vernier, to the angle of inclination suited to the lay of the ground. A slope of 1 in 20, corresponding to 2° 52′, or to within a few minutes of 3°, should be the maximum, except for temporary descent into water-courses, which may be 1 in 12, or 4° 45′. The holder of the forward staff goes on a few yards and is signalled up or down, till the foot of it is resting on the line of the required slope. The tracer has no difficulty in catching the bubble of the level with his eye, at the same moment as he watches the vane of the staff through the pin-hole sight and cross hairs, and as soon as properly placed, he orders a peg to be driven at its foot. He then moves up to the peg, and sends the staff bearer forward to take up a fresh position; and so on till the trace is pegged in. A party follows to open out to one yard, and when the line has been inspected by the Executive Engineer and approved of, to 12 feet; next season the road is finished to the full width, with a side drain.

This simple method of tracing is admirably suited to rough undulating country covered with forest, where an ordinary spirit level cannot be easily carried about or set up; and where extreme accuracy is not imperative as in the case of common roads. Even a practised eye cannot lay out a road on the hill side that would not be found to depart widely from the uniform slope proposed, unless the instrument has been in hand all the time; eye traces as they are termed, should therefore be proscribed, except on flattish ground, where the slavish following of the instrument is apt to lead to the marking of a tortuous line. If a cutting through a saddle or spur has to be made, it is usual to denote its commencement and end, by inserting two pegs instead of one; and at descents into streams, the same course must be observed. Great care should be exercised that the latter are formed with due regard to facility of passage, for many an excellent road trace is marred by insurmountable difficulties at the steep banks of rivers, or headlong ramps. It is neither singular nor surprising, that, upon the principle of rivers [illegible] middle of large towns, the coffee estates of Coorg

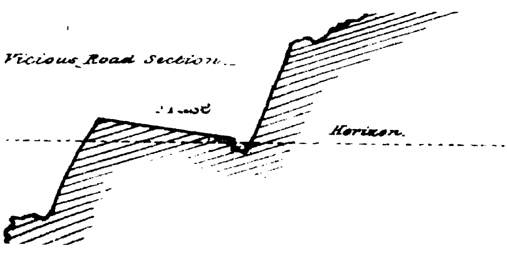

ROAD TRACING IN SOUTH CANARA.
Tracing Quadrant.
A.
B
Forward Staff.
A.
B

the view from any particular point all round, while the sun is seldom visible.

To the Engineer, South Canara is a much less attractive district than North Canara. It has many of its drawbacks, and far less romance about it. Road tracing is troublesome, without being interesting; and possesses a local rather than an imperial importance, now that it is traversable from west to east. It is besides not encouraging to be debarred from completing in a scientific and workman-like manner the bridging of the principal lines, and the formation of their surface, for lack of means, in a country in which the engineering practice not slightly resembles that of Europe; and when he knows that it is real economy to finish them off in a few seasons and after the best models. Nor, if it should fall to his lot to have bridges of any size to erect, is it satisfactory to be tied down indiscriminately from vicious precedent, to so friable and unstable a material as Laterite, or so perishable a substance as timber is in moist situations. But supposing these defects in practice amended, and it were resolved to conduct the works in South Canara upon a broader basis than mere mending and patching, and by a liberal expenditure to complete the system of roads in this small district rapidly and effectually, then there is scope for much professional exertion, and for the achievement of those pleasurable results, which, in stimulated trade, increased capital and intelligence, and a buoyant revenue, so promptly follow on the heels of the Engineer in India. (1865).



SECTIONS OF HILL ROADS.



No. CIV.

THE DOUBLE ISLAND LIGHTHOUSE.

Compiled from the Reports of LIEUT. J. McNEILE, R.E., *Assist. Engineer, in charge of the work.*

IN the last Volume of these Papers a short account was given of the Alguada Lighthouse, off the coast of Burmah, as constructed by Lieut.-Col. Alexander Fraser, R.E. Simultaneously with the progress of that work, a lighthouse was designed and constructed under that Officer's superintendence on Double Island, near the mouth of the Bassein river, in latitude 15° 52′ 30″, longitude 97° 36′ 30″, some account of which, though the work had no such peculiar difficulties as attended the construction of that on the Alguada Reef, will be found interesting and useful to the readers of these Papers.

The original design for the Double Island Lighthouse was for a cut granite tower, but this having been considered too expensive by Government, another design was submitted for a brick tower, with the foundation and lower story of rubble granite; cut stone being employed only for the coping on which the sole-plate of the lantern rests, for the cornice of the balcony, and for the arch over the tower doorway. The total of this estimate, including the light apparatus, amounted to Rs. 61,538. The rubble granite and a portion of the cut stone were prepared at Callagouk during the south-west monsoon of 1862, and work was commenced in October of the same year.

In the following year, Colonel Fraser reports that "the works are progressing in a manner very creditable to Lieutenant McNeile, and the

Overseer, Mr. Nelson. The chief difficulty with this lighthouse has been landing the materials and water. The tide runs from 6 to 7 miles an hour at the spring, and is always very strong; there is a rise and fall of some 20 feet, and as there is no beach and the island is fringed with rocks, there was no protection whatever for boats. By blasting, however, and setting up a small crane, these difficulties have been overcome and a small dock has been formed; and, with the exception of a few things, all the materials required for completing the buildings have been landed. The supply of water has been scant for the building work, and the establishment was adapted to it. It could have been pushed on faster, but there was no object in getting the work completed before the arrival of the lantern."

What follows is abridged from Lieut. McNeile's completion report:—

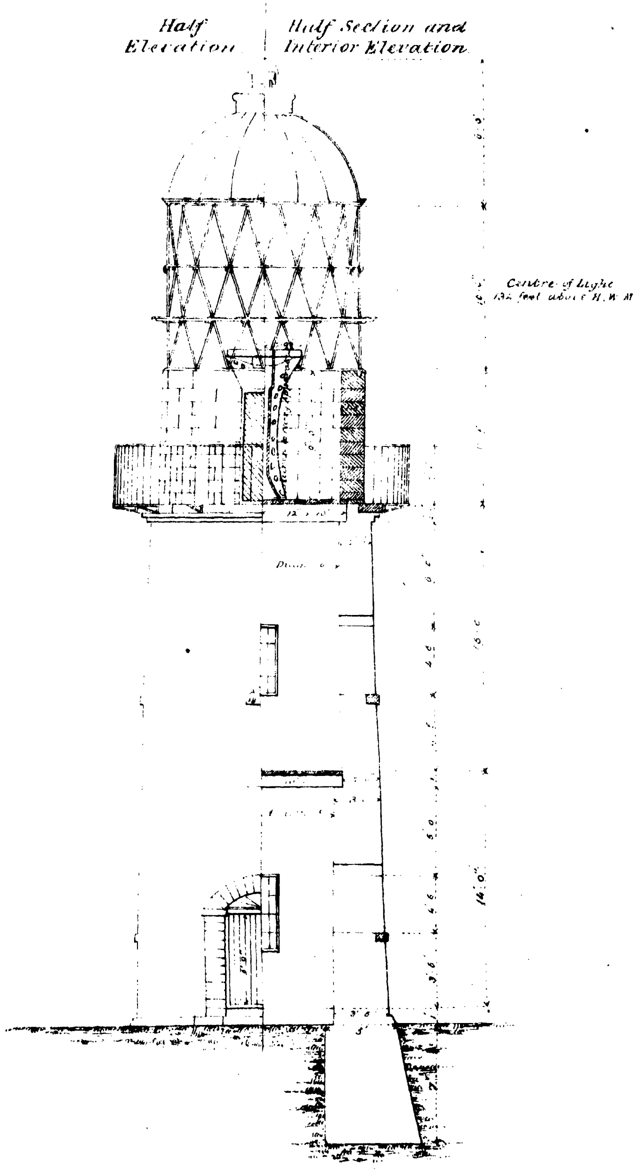
The upper portion of the tower, as far as the balcony, is built of bricks brought from Singapoor by steamer, which are well-shaped and burnt. The bond employed was the "old English." Above the level of the balcony comes the parapet-wall, which is of cut granite, prepared at Callagouk.

I have prepared a drawing to accompany this Report of the Lighthouse Tower as actually completed. The interior of the light-room has been pointed with red-lead, and painted. If this portion of the building had been of brick as originally designed, it would have been necessary to have lined the wall of the Light-room entirely with wood to prevent dust.

The other buildings on Double Island (European and Native Light-keepers' quarters, and cook-house) have been built as designed, and tanks have been supplied for about 1,600 gallons of water, for the use of the establishment. By January 1865, all was ready for erecting the lantern, but owing to delay in its arrival from England, the light was not actually shown until the following December.

Owing to the absence of precise information, the height of the light-room is less than it should have been by about one foot. The result of this is, that a small portion of the light (about one-twentieth of the whole) is intercepted by the upper portion of the lantern. This error in height also involved a little alteration in the steadying rods which connect the frame of the light apparatus with the lantern. In the Alguada Reef Lighthouse on the other hand, the room had been built a little too high (about 6 inches), and there the difficulty was got over by raising the

DOUBLE ISLAND LIGHTHOUSE.



machine case slightly off the floor. The proper dimensions for a Light-room for a first-class light as now constructed, whether fixed or revolving, appear to be—height 10 feet, interior diameter 11 feet 6 inches, and thickness of parapet wall 2 feet or 2 feet 3 inches.

The Lantern is precisely similar to that erected at the Alguada Reef, with the simple alteration of having sheet-iron instead of panes of glass on the non-illuminated side. No difficulty occurred in its erection, which was completed on the 25th November, just a month and two days being thus occupied. This is not a long time considering that the stone-work was not ready to receive the sole-plate, and the large quantity of rivetting in the dome necessarily took sometime.

The lighthouse is supplied with spelter Tanks, similar to those originally used at the Alguada Reef Lighthouse, capable of holding about 800 gallons of oil. To prevent the possibility of their bursting (as happened at the Alguada Reef), they have been cased, by fitting round each tank separately, a frame consisting of four uprights attached to the stand on which the tank is placed, with planking one inch thick, placed horizontally, and screwed firmly to the uprights. The strength of this framing was tested by keeping one of the tanks filled with water for some days. All the tanks have also been tested for leakage. There were originally ten of these tanks, but as the casing necessarily caused them to take up more space, only eight have been placed in the lighthouse, four on each floor, the remaining two being left as spare ones in case of their being hereafter wanted, either at Double Island or elsewhere. The nightly expenditure of oil is about $2\frac{1}{2}$ gallons, so that each tank contains about $1\frac{1}{2}$ months' supply, or in all (eight tanks) nearly twelve months.

While the lantern was being erected, a good opportunity was afforded for getting some of the heavier portions of the Light apparatus into their places. The base consists of a cast-iron column, 9 feet high, in two lengths, strengthened by four cast-iron side brackets, and carrying an iron-table 5 feet 6 inches in diameter, to which the gun metal uprights and slags are screwed. This table also carries the mechanical lamp worked by a weight which passes down the centre of the column. This iron column, though after all of no very great weight, was the heaviest thing that had to be hoisted into its place, and as it was not likely to get damaged, I had it sent up and fixed as soon as possible. It was afterwards, while completing the lantern, very useful as a good firm staging. The remaining portions of the apparatus, though requiring very careful handling, did not take long to put together, and by the 2nd December all was ready for lighting.

The Light is *a fixed dioptric light of the first order, showing through an angle of 180°, a portion (80° 30′) being darkened.* It consists of a single flame $3\frac{1}{2}$ inches in diameter, having four concentric wicks, and fed by a mechanical lamp. This lamp requires to be wound up every four hours; and, as a general rule, with good clear oil, the wicks require to be trimmed only once during the night, supposing them of course to have been properly trimmed before being lit. The light issuing forward is bent into the direction of the horizon by refracting prismatic zones of glass, while that escaping behind (towards the dark part of the lantern) is returned by a totally reflecting glass mirror through the focus, and eventually directed by the glass prisms as if it had originally issued in the opposite direction. The number of prisms and their form and position (approximately) are shown in the accompanying drawing.

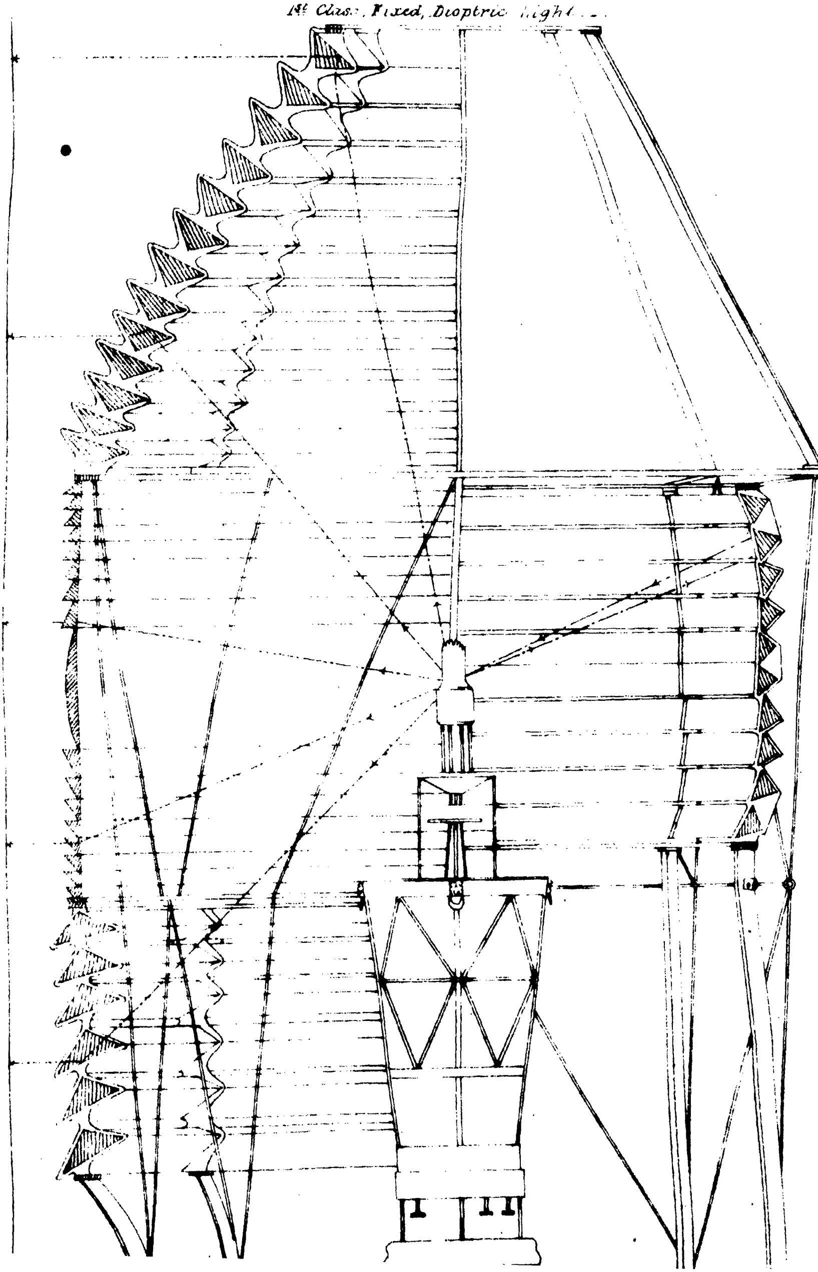
The centre of the light is 134 feet above high-water mark, and should therefore be visible from the deck of a large ship, (say 20 feet high,) at a distance of $18\frac{3}{4}$ nautical miles. The rise and fall at spring tides being about 20 feet, the above distance would at low water be increased to $19\frac{3}{4}$ nautical or $22\frac{3}{4}$ statute miles. On the night of the 6th I went down in the schooner *Amherstia* nearly as far as Callagouk to judge of the appearance of the light; the tide prevented our getting more than about 17 miles, at which distance the light was visible from her deck (about 10 feet from the water) bright and clear.

The works at Double Island were originally commenced early in 1862, so that at first sight they appear to have occupied a long time. However, if allowance be made for work having been stopped (except once) during the south-west monsoon, for the difficulty of supplying sufficient fresh water for building, and of landing materials, and for the delay in receiving the lantern and light apparatus, (for which the buildings were ready nearly a year ago,) it will be seen that the time actually employed is not excessive.

The second sea lighthouse on the coast of Burmah has thus been successfully established, and, though not in itself a work to bear comparison with the Alguada Reef Lighthouse, still it has not been completed without a good deal of discomfort, and hard, if not hazardous, work.

DOUBLE ISLAND LIGHTHOUSE.

Section and Interior Elevation,
1st Class, Fixed, Dioptric Light.



No. CV.

THE GREAT INDIAN PENINSULA RAILWAY.

Description of the line and works of the G. I. P. Railway, by J. J BERKLEY, ESQ., M. Inst. C.E. *Abridged, by permission, from the Minutes of Proceedings of the Institution, for* 1859-60.

THE Great Indian Peninsula Railway will (when completed) extend from the port and city of Bombay, to join the East Indian Line at Jubbulpore on the north-east, with a long branch to Nagpore; and to join the Madras Line on the southeast, at or about the river Kristna.

Bombay, the western terminus to which the trunk lines and all others connected with the undertaking, converge, is a justly celebrated port. Its population now numbers about 700,000, consisting of Europeans and Asiatics of all castes and races. The advantages of its situation, in the centre of the western coast of the peninsula of India, and of its safe and capacious harbour, are obvious; and these, as well as the recent preponderance of trade, distinguish it as the commercial capital of India. It is the depôt of the Indian navy, and the tonnage of the port in 1858-59, amounted to 1,353,000 tons.

It exported, in 1859, 206,915,874 lbs. of cotton, valued at £3,957,639 sterling. The produce of the customs has risen from £3,024,000 to £6,169,200 per annum, more than double, in only five years. Its commerce in merchandise and treasure amount, for 1858-59, to a total of £34,332,423, the imports being £18,381,541, and the exports, £15,950,882, or £9,000,000 more than the whole foreign commerce of India, in the year 1848.

The chief imports are:—cotton and woollen goods, machinery, metals, wine, spirits and malt liquors, military and naval stores, railway materials, ivory, spices, silk, sugar, tea, coffee, tobacco, horses, drugs and dyes, fruits, precious stones, books and stationery, grain, seed, oil, timber, ice, *apparel and treasure. These are derived from the United Kingdom, Africa, China, Penang, Singapore, the Straits of Malacca, the Persian Gulf, Suez, Calcutta, Malabar, North America, the Arabian Gulf, Batavia and* Java, Ceylon, France, the Mauritius, Aden, Cutch and Guzerat.

The chief exports are:—cotton, hides and skins, oils, saltpetre, seeds, Cashmere shawls, wool, opium, coffee, dyes, sugar, tea, grain, provisions, precious stones, beads, metals, spices, salt and fruits; and they are generally consigned to the same places whence the imports are derived.

With this port and metropolis as a western terminus, the Great Indian Peninsula Railway will command a portion of the great traffic of the North-western Provinces of India; the opium fields of Malwa; the grain and seed provinces of the valley of the Nerbudda; the vast cotton fields of Berar, of the Nizam's dominions and of Sholapore; and the trans-peninsula traffic from Calcutta and Madras.

The Syhadree mountains, or as they are commonly called, the Ghauts, intercept the channel of communication for this vast and important traffic. They lie parallel to the coast, from which they are distant about 30 miles, and, in a range of about 100 miles, there are only two main roads by which wheeled traffic can cross them; the Agra road up the Thul Ghaut and the Poona and Calcutta road, up the Bhore Ghaut. The rest of the passes are rough tracks, fit only for the use of pack-bullocks.

When regarded as a means of conveyance for a rich and extensive tract of country, capable of sending to a central port like Bombay, a large amount of produce, to supply the demands of distant competing markets, the principal characteristics of the existing roads and means of transport in the Bombay Presidency are:—extreme slowness, only about twelve miles per day,—uncontrollable irregularity,—great cost of conveyance, amounting to $3\frac{1}{4}d.$ to $4\frac{1}{2}d.$ per ton, per mile,—the short duration of the favorable season for conveyance,—the limited extent of the present means of carriage,—and the damage to goods, and losses by theft and from bad weather, upon the journey.

The first section undertaken by the Great Indian Peninsula Railway Company, was that from Bombay to Callian, 33 miles, with a branch to

Mahim of $1\frac{1}{2}$ miles; it was called the "Experimental Line." It was begun by Messrs. Faviell and Fowler in February, 1851, and was finished by them, in conjunction with Messrs. Wythes and Jackson, and Mr. Jamsetjee Dorabjee, a Parsee, in April 1854. The portion from Bombay to Tannah, a distance of 20 miles, was the first railway opened in India for *public traffic, which event took place on the 16th of April, 1853. From Bombay to Callian, a double line of rails has been laid. Its steepest gradient is 1 in 150, and the radius of the sharpest curve is 40 chains. The Bombay* terminus is at Boree Bunder, having the advantage of a quay frontage to the harbour, and although it occupies an area of 19 acres, it is already overcrowded. The site not being permanent, all the buildings are of a temporary character. The Company's depôt for working the lines is situated at Byculloh, about 2 miles from the terminus. It covers an area of $18\frac{3}{4}$ acres, and contains steam sheds, erecting and fitting shops, smithies, iron and brass foundries, saw mill, carriage-repairing and waggon-building sheds, stores, warehouses, coke shed, a timber-preserving establishment, offices, and workmens' and engine-drivers' dwelling-houses.

The principal works upon the Experimental Line are the crossing of the Sion Marsh, which is effected by an embankment; the crossing of the arm of the sea from the island of Salsette to the Concan, comprising two viaducts, the length respectively, of 111 yards and 193 yards, in the latter of which there is an opening for navigation, of 84 feet, spanned by wrought-iron plate girders; beyond this, there are two tunnels of the respective lengths of 103 yards and 115 yards. The railway is protected by post and rail fences, and prickly-pear and cactus hedges. The station buildings are of masonry. The permanent way is chiefly laid with transverse wooden sleepers, and 6 miles of it with iron pot-sleepers. The rails, which are of the double **T** form, weigh 84 lbs. per lineal yard, as far as Tannah; beyond which place, they weigh only 65 lbs. and 68 lbs. per yard. The lighter rails extend along the whole of the Company's main lines, except the two Ghaut Inclines, on which are laid rails of 85 lbs. per yard. From Callian diverge,—the South-Eastern Extension to Poonah and Sholapore, and its proposed prolongation to the river Kristna and the Madras Railway,—and the North-Eastern Extension to Nassick and Jubbulpore, to join the East Indian Railway from Calcutta, by which a communication will also be effected with the North-Western Provinces of India.

S. E. Extension.—The first section of the South-Eastern Extension is from Callian to Campoolee, at the foot of the Bhore Ghaut mail-road. It is $37\frac{3}{4}$ miles in length, of which $30\frac{1}{4}$ miles, to the foot of the railway incline, are permanent, the remainder having been designed for temporary use, until the Ghaut Incline was opened. This portion of the railway was begun by Mr. Jamsetjee Dorabjee in 1854, and was finished in 1856. It has been constructed for a double line, but only one road has been laid. Its ruling gradient is 1 in 115 on the permanent, and 1 in 85 on the temporary, portion. The radius of its sharpest curve is 40 chains. It contains no work of any special character, but it is remarkable for the extraordinary floods and rapid torrents to which it is exposed on both sides. The bridges and culverts are built of rubble masonry, with coursed facework; and in one or two instances, cast-iron girders were made use of. The average cost of this section, exclusive of rolling stock, was only £4,500 per mile.

*Bhore Ghaut Incline.**—Four years were spent in preliminary surveys of this incline, and in laying out and preparing cross sections, to the number of about two thousand, and perhaps the most difficult that have ever been taken. Four years more have already expired since the contractor commenced operations upon it. The works were begun by Mr. Faviell in January 1856, and taken up in November 1859, by Mr. S. Tredwell, whose melancholy death within a month of his arrival in India, many members of the profession must sincerely lament. It is expected to be finished about three years hence.† It is 15 miles 68 chains in length, and the total rise is 1,831 feet. Its average gradient is 1 in 48. The steepest gradients are 1 in 37, extending in one length for 1 mile 10 chains, and 1 in 40 for 5 miles 6 chains. Short lengths of level gradients and of 1 in 330 are introduced into this incline, to facilitate the ascent of the engine. The radii of the curves upon it range from 15 chains to 80 chains, and 5 miles 33 chains are straight. It comprises twenty-five tunnels, of a total length of 3,585 yards. The longest is 437 yards; and the longest without a shaft, which is carried through a mountain of basalt, is 346 yards. There are eight viaducts of a total length of 987 yards. The two largest are 168 yards long, and respectively, 163 feet and 160 feet above the foundations. The viaducts are being built, up to the surface of the ground, of solid

* See Vol. I., p. 48.—[Ed.]

† Since completed and opened for traffic; the total cost has been £1,100,000.—[Ed.]

block-in-course masonry, and above, of block-in-course facework, strongly tied through, by header bonds of block-in-course, to the internal work of sound rubble, and with coursed rubble arches. The contract also comprises a large quantity of retaining walls. The total quantity of cutting, chiefly rock, amounts, by calculation, to 1,263,102 cubic yards. The maximum depth of cutting is 70 feet, and the greatest contents, 75,000 cubic yards of trap rock. The embankments amount to 1,849,934 cubic yards, the maximum height being 74 feet; and greatest contents are 209,000 and 263,000 cubic yards. The slopes average about $1\frac{1}{2}$ to 1. There are twenty-three bridges of various spans, from 7 feet to 30 feet, and sixty culverts from 2 feet to 6 feet wide. The rails weigh 85 lbs. per yard, and are laid with fish joints, with small cast-iron saddles under the joints, resting upon longitudinal planks, the ends of which bear upon, and are secured by fang bolts, to transverse wooden sleepers. The estimated cost of this incline is £750,000. The upper 2 miles from Khandalla to Lanowlee, with gradients of 1 in 40 and 1 in 50, were opened on the 14th of June, 1858, and have since been worked with safety and regularity.

At the eleventh mile, the incline is divided into two banks, by what is called a reversing station. This sub-division, however, was not adopted for the purpose of making two banks of the incline, but of increasing the length of the base, in order to flatten the gradient and to reach a higher level, where it encountered the great features of the Ghaut margin, near Khandalla. Without the necessary expedient of the reversing station, the practicability of changing the direction of the line would have been confined to making curves of small radius; but with the device of the reversing station, the direction was altered at a very acute angle, by means of points and crossings. In consequence of its adoption, the incline is prolonged by nearly the difference between the length of the two sides of an acute-angled triangle, and that of its base.

The peculiar difficulties upon this incline are the unfavorable nature of the hot and rainy seasons; the fatal epidemics which dismay and disperse the people employed upon it; the lofty and precipitous character of the ground, which impedes the haulage of materials and harasses all who are engaged in the operations; the extensive and sudden slips upon the mountain sides; the extreme hardness and solidity of the rocks; the scarcity of water; and the want of necessaries and comforts for the men.

The next section of the South-Eastern Extension is from Lanowlee, the summit of the Bhore Ghaut Incline, to Poonah and Sholapore, and is $205\frac{1}{2}$ miles in length. The first 42 miles were begun by Mr. Faviell in January 1856, and were finished in June 1858. The remaining $163\frac{3}{4}$ miles were commenced by Mr. J. Bray, in March 1856, and 143 miles completed on the 27th of December, 1859. Its engineering character is very similar to that of the Concan section. Its ruling gradient is 1 in 132, and the radius of its sharpest curve is 40 chains. The cuttings are in trap rock, moorum, and soil; and the embankments are chiefly composed of soil and moorum. There are twenty-two viaducts, three hundred and fifty-nine bridges, and four hundred and fifty-four culverts, all built of substantial masonry. The largest works are the viaducts over the Beema, 441 yards long and 60 feet high, consisting of twenty-eight segmental arches 40 feet in span, with a flood stream 46 feet deep, and rock foundations, the cost of which was £24,246; and that over the river Seena, 190 yards long, 54 feet high, consisting of twelve segmental arches 40 feet in span, with a flood stream 41 feet deep, and foundations partly in rock and partly on hard clay. The fences are dry rubble walls, and cast-iron posts and iron-wire rails. One peculiarity of this district is the violence and suddenness of the floods, which descend with scarcely an hour's notice, and gather into torrents on spots upon which there is no trace or warning of any stream. In the uncommenced portion of the South-Eastern Extension, from Sholapore to the junction with the Madras Line, in the Raichore district, there will be two very large viaducts over the rivers Beema and Kristna. Upon the South-Eastern Extension large quantities of cotton and country produce are now carried, and it is evident that an immense traffic must soon be accommodated. The earthwork has been executed for a single line, and the viaducts and bridges for a double line.

N. E. Extension.—Returning to Callian, the first section of the North-Eastern Extension, which there diverges towards Jubbulpore and Calcutta, is from Callian to Kussarah, 26 miles, gradually climbing, by steep gradients, of which a great portion are 1 in 100, the flank of a long mountain spur, which projects from the Ghaut range, and divides the valley of the Basta on the south, from the Wyturnee on the north. This section is full of heavy work; but to obtain even such a line, demanded a long and minute study of the rugged and jungle-covered district. The works have been executed by Mr. Jamsetjee Dorabjee. The radius of the sharpest curve is

30 chains. It contains 520,493 yards of cutting, chiefly trap and basaltic rock, and 1,353,317 cubic yards of embankment. It comprises four viaducts, of which the two largest are respectively, 124 yards and 143 yards long, and 127 feet and 122 feet high; forty-four bridges from 7 feet to 30 feet in span, and one hundred and seventeen culverts. By means of this section, 849 feet of the ascent have been surmounted to the summit of the Ghaut, and thus the altitude to be overcome by the Thul Ghaut Incline is reduced to only 972 feet.

Thul Ghaut Incline.—The Thul Ghaut Incline extends from the village of Kussarah to Egutpoora, and is in course of construction by Messrs. Wythes and Jackson. It is $9\frac{1}{2}$ miles in length, and has a total ascent of 972 feet. At the end of $3\frac{3}{4}$ miles there is a reversing station, similar to that upon the Bhore Ghaut Incline, by which the base was lengthened, the gradient flattened, and the incline divided into two banks. The steepest gradient is 1 in 37, for a length of 4 miles 30 chains; and the same introduction of a level portion is adopted here as on the Bhore Ghaut. The radius of the curves ranges from 17 chains to 100 chains, and 3 miles 28 chains are straight. There are 13 tunnels, of a total length of 2,652 yards. The longest are, one of 474 yards, in black basalt, with two shafts, and another of 483 yards, without a shaft, in greenstone. There are six viaducts, of a total length of 741 yards, the largest of which are respectively, 144 and 250 yards long, and 83 feet and 182 feet high. The latter is designed for three spans of triangular iron girders measuring 150 feet, with a pair of semi-circular abutment arches, measuring 40 feet at each end. There are fifteen bridges, of which the span varies from 7 feet to 30 feet, and sixty-two culverts. The cost of the incline will be about £450,000. The preliminary surveys and studies occupied four years, and the works were commenced in October, 1857.

The next section of the North-Eastern Extension runs from the summit of the Thul Ghaut Incline, at Egutpoora, by Nassick, across the fertile valley of the Godavery, and the Indhadree range of mountains, along Khandeish to Bhosawul, the point of junction with the Oomrawuttee and Nagpore Branch. The character of this line is very similar to the corresponding section of the South-Eastern Extension, from the Bhore Ghaut to Sholapore, and the nature of the earthwork is much the same. The principal works upon it are:—a viaduct over the Godavery, 145 yards in length, consisting of nine arches 40 feet in span, with a flood stream 36 feet deep, and foundations upon rock, excavated through sand; the Kadoo Viaduct, 242 yards in length, with fifteen arches 40 feet in span; the Munnair Viaduct, with five openings spanned by triangular iron girders, and two pairs of abutment arches; and the Waugoor Viaduct, with ten openings, also spanned by triangular iron girders. This section contains twenty viaducts, two hundred and seventy-nine bridges, and four hundred and thirty-five culverts. It was commenced by Messrs. Wythes and Jackson, in October, 1857.

The last section of the North-Eastern Extension runs from Bhosawul to Jubbulpore. It is 328 miles in length, and was contracted for by Messrs. Duckett and Stead, in January, 1859. As the operations are in a preliminary state, it is only necessary to notice the two very large viaducts over the rivers Taptee and Nerbudda. The Taptee Viaduct is 875 yards long, consisting of five openings of 138 feet and fourteen openings of 60 feet, and twenty arches 40 feet in span, with a flood stream 70 feet in depth, and foundations upon rocks. The Nerbudda Viaduct will be about 387 yards long, 100 feet high, with a flood stream 90 feet deep.

The Oomrawuttee and Nagpore Branch is about 263 miles in length. It was let to Messrs. Lee, Watson, and Aiton, who are now just commencing operations. As the line has not yet been entirely staked out, no details can, at present, be given; but its general character is known to be favorable, and the works are light. The largest works will be the viaducts over the rivers Nalgunge and Wurdah.

There is no tunnel beyond the Ghauts, upon any of the lines now under construction, comprising a length of 782 miles.

The following fundamental points are observed and carried out with the greatest practicable economy and despatch, in the completion of this system of railways. The character of the main lines is plain, substantial, and durable, and such as will provide for the regular and expeditious conveyance of a heavy and increasing traffic in goods, and the accommodation of a great number of passengers, at a moderate working cost, and at a reasonable expenditure in maintenance.

The geological nature of the country is volcanic; the hills and mountains consist of trap rock and *laterite*, a kind of ferruginous clay, so called from its frequent resemblance to brick. Granite hills protrude in the southern Mahratta country below Sholapore. The trap is of various sorts, more or less earthy, or crystalline, and the hills have almost invariably, either a crest or axis of basalt; their surface is bare, or covered with what is called in India, *moorum*. The basalt, sometimes highly porphyritic, is nodular, rectangular, tabular, and columnar. Moorum is of a reddish, or gray color, and is, no doubt decomposed rock of a very earthy nature; in the cuttings, it is found both hard and soft. In the valleys, there is a great depth of vegetable soil.

As favouring engineering operations, the indestructible nature of the slopes of cuttings and embankments made of the black soil; the facility of excavating moorum, its firmness for slopes and embankments, and frequent suitability for ballast; the advantage of having rock foundations for the crossing of rivers and streams, and also that of making tunnels without either lining or faces; and the fine quality of the stone for building purposes and the facilities of quarrying it, are worthy of special notice. As a set-off to these advantages, there are the extreme hardness of the black basalt, which renders progress both tardy and expensive, and the precipitous altitude of the mountains, which in many cases, prevents the sinking of shafts, and thus limits the mining of tunnels to the two faces only.

Among the geological features, the existence of large quantities of *kunkur*, a variety of fresh water limestone, and the want of good brick earth, must be mentioned.

The physical geography of the districts of Western India traversed by the Great Indian Peninsula lines, may be thus briefly described. First, the plain of the Concan, elevated very little above the level of the sea; then the abrupt scarp of the Syhadree mountains, the least altitude of which above the sea, is about 2,200 feet; and beyond that, the plain of the Deccan on the South-Eastern Extension, gradually sloping down towards the eastern coast of India: whilst upon the North-Eastern Extension, the country presents the bold features of the rivers Taptee and Nerbudda, with three paralled chains of mountains called the Indyhadree, the Santpoora, and the Vyndhya ranges.

The physical character of the country is less favorable to the Railway Engineer than it might appear, in consequence of the extraordinary quantity of rain which falls upon the western coast during the monsoon, a period of four months from June to September. The line of the Ghauts is the axis of these rains, and the rivers and streams which rise in it are either dry or stagnant, during the fine weather, and become deep and violent torrents during the monsoon. The height of known floods, where the railway crosses some of the principal rivers varies from 25 feet at the Waldhur, to about 70 feet at the Taptee, and about 90 feet at the Nerbudda. Extreme difficulty has been experienced in ascertaining the *maximum heights of floods, not merely in the rivers, but in most of the numerous streams which it was necessary to cross. There is nothing* upon the ground to indicate them, and the information obtained by careful and extensive inquiry has, generally, been of the most inconsistent nature. Some idea of this difficulty may be conveyed by the fact, that in the year 1837, the river Taptee, where the railway crosses it, rose 30 feet above the highest level it has since attained.

Railway Materials.—The railway materials procurable in India are—iron, coal, timber, stone, bricks, lime, gunpowder, and ballast. Indian coal and iron are very seldom seen in the Bombay market. In many parts of the Nerbudda valley, coal exists of excellent quality and in great abundance, and it lies in a favorable position for being worked. Iron ore, too, abounds, especially on the right bank of the Nerbudda. The principal mines of the district are those at Tenderkaira, near Nursingpoor, about ten miles from the Great Indian Peninsula Line. They are now worked in the rudest fashion, but the iron produced is of excellent quality. There are furnaces also at Paneghur and Gosulpoor, close to which the railway passes, and although the iron is deemed inferior to that of Tenderkaira, it is good, and forms an article of export from those towns. Valuable iron mines also exist at Poonassa and Chandghur, and there are five mines within twenty miles of Jubbulpore. Productive, however, as these may hereafter prove, it is evident that active and successful operations in the manufacture of Indian iron, or the supply of coal, depend more upon the completion of railway communications, than the railway depends upon a local supply of these materials.

The various kinds of wood procurable for railway purposes are of unusually good qualilty. The properties of some which have already been extensively used, are represented in the following statement, the specimens experimented upon being 7 feet in length by 2 inches square in section, a size adopted in previous experiments.

It has not been found necessary to make use of timber in the permathey are seldom of suitable quality for railway works. Moderately good bricks have been, occasionally, procured and used in arches, but to obtain them, a proportion of only 23 per cent. has been selected from the best native kilns. The price ranges from 10*s.* to 24*s.* per thousand. The former rate is for small-sized bricks of inferior quality; the latter are good bricks made of the English size. The lime is of a remarkably fine quality, and is hydraulic. In making *chunam*, or mortar, one part of lime is mixed with two parts of sand. It sets rapidly, so as to give immediate stability to the work, and continues to do so for twelve or fifteen months, until it becomes as hard as the rock itself. Saltpetre and charcoal being easily procurable in the country, gunpowder is largely manufactured. It is very strong and suitable for blasting, and costs, when made upon the spot, about £34 per ton. The ballast consists of sand, broken stones, gray moorum, and nodular basalt.

The Bombay and district markets have greatly varied, and have been sometimes found unfavourable for extensive dealings. The railway demands being unusually large, have occasionally been met by a combination of native merchants, who find it easy to establish a monopoly amongst themselves, and to work it to their profit. This movement has been defeated by a variety of expedients, such as obtaining supplies from the Government stores, procuring the articles direct from the depôt, making them by the Company's own agency, or importing them from England. The result, however, has been a great augmentation of prices and considerable irregularity in obtaining supplies. It is one remarkable feature in Indian railway practice, that a very large, and certainly the most expensive, portion of the materials, has to be supplied from England; a circumstance which not only affects the cost, but also the progress of the works. Experience has already established the fact, that the period requisite for finishing a line for the use of public traffic in the interior of India, is not determined by the local execution of the works, but is dependent upon the delivery along the line of the permanent-way materials, station machinery, and rolling stock, which have to be procured in England, shipped to Bombay, and thence transported to the various districts of the railway.

During the year 1858-59, the shipments to Bombay of permanent-way materials, rolling stock, machinery, and miscellaneous stores, amounted to to 66,937 tons, against 51,386 tons shipped in the previous year. The average sum paid in the year, for freight, was £2 0*s.* 9*d.* per ton of dead weight, the lowest rate, 20*s.* per ton, having been paid in July, 1858, and the highest rate, 60*s.* per ton, in June, 1859; an increase of 29 per cent. upon the average rate of the previous year.

Many of the articles sent from England have been specially designed for Indian use, their main principles being strength, simplicity, and durability, with as much regard to facility of transport as those essential properties would admit.

Greaves' iron sleepers, as used by Mr. Robert Stephenson in Egypt, have been laid on portions of the Great Indian Peninsula Railway, not however, on account of any objections to the wooden sleepers procured in the country, but because of the difficulty of obtaining a sufficient and timely supply of them. A store of English iron sleepers has, therefore, been found convenient for meeting emergencies, and experience has shown that they are handy for transport, quickly and well laid by native laborers, and that they make a good and durable permanent way. A few consignments of creosoted sleepers have also been despatched to Bombay. They proved to be more expensive than Indian wooden sleepers, and were also very liable to split during exposure, between the time of landing and their being laid down. A complete apparatus has been sent out and fitted in Bombay, for dressing timber with corrosive sublimate; as the climate has proved favourable for kyanising. The Indian sleepers which have been dressed, have absorbed about 3¼ gallons of corrosive sublimate; and the cost, including haulage, has been 1*s.* 6*d.* per sleeper.

An iron goods-shed and an iron booking-office were supplied from England, in 1853. Their comparative dearness may, perhaps, be compensated for by their durability and cheapness in repairing, and they are convenient for removal; but on account of their great heat, they have been unsuccessful, notwithstanding well-devised means of ventilation. In future, any iron buildings imported from England, should consist merely of framework, the large surfaces in the sides and upon the roof being afterwards filled in with non-conducting Indian materials.

Native Labor.—Native labor, by which these works have been executed, is cheap, but very inferior to that of England. Nearly one hundred thousand men have been employed upon the Great Indian Peninsula Railway lines at the same time, and as many as forty-two thousand upon the Bhore

Ghaut Incline, which is 15$\frac{3}{4}$ miles in length. This great force has not been collected without considerable trouble; it is not entirely supplied by the local districts, but is gathered from distant sources. Laborers sometimes tramp *for work as in England, and on the same work may be seen men from Lucknow, Guzerat, and Sattara. The wants of the works have, however*, been supplied by unusual exertions in sending messengers in all directions, and by making advances to *muccadums*, or gangers, upon a promise to join the work with bodies of men at the proper season. Country artisans and skilled laborers have their own methods of doing work, but are capable of improvement and are not averse to change their practice. For operations requiring physical strength the low-caste natives, who eat flesh and drink spirits, are the best; but for all the better kinds of workmanship, masonry, bricklaying, carpentry, for instance, the higher castes surpass them. Miners are, on the whole, the best class in the country. The natives strictly observe their caste regulations, yet will readily fall into an organisation upon particular works, to which they will faithfully adhere, and in which they are by no means devoid of interest. Although they cling closely to their gangers, they will attach themselves to those European inspectors who treat them kindly. The effective work of almost every individual laborer in India, falls far short of the result obtained in England. This is a disadvantage upon works, the dimensions, and proper mode of execution of which, limit the number of men that can be employed at one time, because the rate of progress is proportionally diminished. The fine season of eight months is favorable for Indian railway operations, but on the other hand, fatal epidemics, such as cholera and fever, often break out, and the laborers are generally of such a feeble constitution, and so badly provided with shelter and clothing, that they speedily succumb to those diseases, and the benefits of the fine weather are thereby temporarily lost. They work under the immediate control of a ganger, or muccadum, and the various gangs under a mistry or native foreman; and the whole under the inspection of a European overseer of works, by whom interpreters are also usually required. Not only men, but women and children, are employed upon Indian works; and thus, although the wages of the individual are small, the earnings of his family are by no means inconsiderable. The present rates of wages, per day, of the several classes of native laborers are:—

	s.	d.
Native Mistries, or Foremen of Masonry, Brickwork, or Carpentry, ...	2	6
Masons, ...	1	9
Bricklayers, ...	1	3
Carpenters, ...	1	6
Smiths, ...	2	0
Miners (a very large class), ...	0	9
Excavators, ...	0	7½
Laborers, ...	0	6

These rates are very low as compared with English wages, but allowing for the comparatively small effectiveness of Indian labor, the following may be safely taken as the relative cost of each kind of labor, in England and the Bombay Presidency:—

Classes of Labor.	Proportion of Work done by each.		Relative cost of Labor in in each Country.	
	England.	Bombay.	England.	Bombay.
Masons, ...	2½	1	1⅛	1
Bricklayers, ...	4	1	1	1
Carpenters, ...	3	1	1⅛	1
Miners, ...	3	1	2¼	1
Excavators, ...	4	1	1½	1
Laborers, ...	3½	1	1⅝	1

In examining this Table, it should be borne in mind, that the comparison is between simple labor only, and that it does not represent the cost of finished work; for the economy in favor of India suffers, from the expense of obtaining the powerful aid of English appliances, from defective and clumsy methods, and from a variety of drawbacks and disadvantages peculiar to native customs. Strikes, although of rare occurrence, have occasionally taken place, and the truck system, commonly discountenanced at home, is beneficial in India.

The whole of the Great Indian Peninsula Railway has been successfully executed by contract. Speaking generally, the European contractors, have as a rule, been more successful than natives, because the native tenders for the principal contracts have, usually, been eithêr too high, or unreasonably low, so that, looking to their inexperience of such works, it has not often been thought desirable to take advantage of their agency, in the construction of the main lines. There has, however, been one remarkable instance of the employment of native enterprise; a Parsee contractor, Mr. Jamsetjee Dorabjee, has executed four main-line contracts as satisfactorily, as expeditiously, and as cheaply, as any of the European firms, and is now about completing his fifth, which comprises some of the heaviest works on the lines.

In the other respects, native agency has been employed and encouraged, as much as possible. The Company's Engineers, Assistant Engineers, and Surveyors are generally Europeans, but one native Engineer has won his way to the office of Assistant Engineer, and has skilfully discharged its duties for three years. In the office establishment of draftsmen, accountants, and clerks, all the situations have been held by natives. As inspectors of work, natives have been chiefly employed. As district inspectors of the line, when opened, native agency is already partially adopted and is, by encouragement, gradually becoming more useful.

In the methods of executing the works two objects have to be kept in view; first, to turn those of the natives to the best account; and secondly, to introduce English appliances where it can be done with advantage. It has not always been obvious which of these measures would, under the circumstances, be the more effectual, and experience has taught that some Indian modes of doing work, which seemed barbarous and clumsy, were the cheapest and quickest means which could be employed.

Tunnels may be said to be an entirely new description of work in Western India, and the whole process, except blasting and excavation, was unknown to native workmen. In the earliest tunnels, where the top was heavy, it was found, at first, impossible to keep native miners in the heading, and the timbering was done chiefly by Europeans and one or two Parsee carpenters, and the arch was keyed in by the former alone. Native miners use the churn drill, with which they are very handy, and they have sometimes been brought to work in pairs with the hammer, and strike with dexterity. They will work hard in close contact and in the foulest atmosphere. They are careless in blasting operations, and consequently, the loss of life has been considerable; miners have been seen to fire a shot with a bamboo, and lie upon the ground while it exploded.

In building viaducts and bridges, there is a mixture of appliances and operations. In pumping foundations, English pumps only are sometimes and by the Mahratta *môth,* a leather bag containing about 35 gallons of water, which is lowered and lifted over a pulley by bullock power. The natives also have various hand devices for scooping or baling water from the bridge pits, all of which are occasionally resorted to. Where water has to be brought, it is carried in leather bags called *puckals*, laden in pairs on bullocks' backs. In some districts, it is thus conveyed more than two miles to the masonry.

In staging and scaffolding, it is only rarely and in very large works, that the English example has been followed, nor are crabs and derricks so often met with as might be expected. The reason for this is afforded by experience, which has taught how cheap and expeditious it sometimes is, to use the native process. The bamboo coolies, or carriers of heavy weights, will lift their loads up the roughest staging, and the masons and laborers require but little help, to find their way to the work at the top of the highest piers. The centering commonly adopted in the country, was to fill up the arch with stone and earth, and to shape the top to the form of the soffit, or at other times, to use almost a forest of jungle wood in scaffolding a rough centre. For these, centres of English construction have invariably been substituted, with, as may be conceived, immense advantage to the work.

The native sawyers always work in pairs, even in the smallest jobs. The sawing is so inferior that a great deal of adzing is requisite, and much of the work that would be planed in England, is turned out roughly with the adze in Bombay. In planing there is the same peculiarity of working in pairs; carpenters squat to their work, and it is with extreme difficulty that a few of them have been brought to stand to a bench. It is remarkable to observe how freely they call in the aid of their feet; a carpenter may be seen resting his weight upon one foot, and cleaning his axe with the sole of the other.

In making embankments, the Hindoo custom of carrying the earth in baskets upon the head, is, owing to the cheapness of land for side cuttings, found more economical than wagon roads with long "leads," and, judging by the result, it is attended with very little sacrifice of despatch. Within one month, 30,000 cubic yards have been put, by this means, into an embankment only 24 chains in length.

Smiths' and foundry work is moderately good, but the class being so small and the material being English, almost all supplies of manufactured iron have had to be procured from England. Plate-laying was of course entirely a new operation, yet a large quantity of excellent work has been turned out by native labor under close inspection.

Among the mechanical improvements and innovations made by railway construction, may be enumerated, the use of barrows, dobbin carts, wagons and wagon roads, lorries, both wooden and iron, water pumps, crabs, moulding tables for brickmaking, stationary-engine power for sawing, pumping, and working tunnel shafts, hammer drilling, bridge centering, pile driving, timber pickling, and various kinds of iron superstructure for bridges.

The average cost of the opened portions of the line has been from about £8,000 to £9,000 per mile.

The prices of the principal kinds of work, including all the usual contract stipulations, have ranged as follows :—

			£.	s.	d.		£.	s.	d.
Earthwork in embankment under a quarter of a mile lead,	per cubic yard,	from	0	0	6	to	0	0	7½
Cutting in earth, or moorum, ditto,	,,		0	0	7½	,,	0	0	9
Ditto in rock, ditto,	,,		0	1	1	,,	0	2	6
Tunnel,	,,		21	10	0	,,	33	0	0
Brickwork in arches, ...	,,		0	15	0	,,	1	10	0
Coursed rubble masonry in ditto, .	,,		1	7	0	,,	1	16	0
Ashlar, ...	cubic foot		0	1	7½	,,	0	3	0
Block in course, ...	cubic yard		0	16	0	,,	1	15	0
Coursed rubble, ...	,,		0	14	0	,,	1	4	0
Rubble, ...	,,		0	9	0	,,	0	14	0
Woodwork (teak), ...	cubic foot		0	4	0	,,	0	6	0
Ballast, ...	cubic yard		0	1	1½	,,	0	1	4½
Laying permanent road, ...	lineal yard		0	2	0	,,	0	2	10½
Post and rail fence, ...	,,		0	1	6	,,	0	2	0
Dry rubble wall, ...	,,		0	2	6	,,	0	4	0

This does not include the Ghaut Inclines, which are exceptional.

The total length of the G. I. P. Railway will be 1,114 miles, of which 508 were opened up to 1863. The estimated cost was about £10,000 per mile; and the total expenditure up to 1st May 1863, was £9,877,615.

The locomotives employed on the line have cylinders 15 inches in diameter, with a stroke of 22 inches; and four coupled wheels, each 5 feet 6 inches in diameter. Those in use upon the inclines are tank engines, having cylinders 15 inches in diameter, with stroke of 2 feet; and four wheels, each 4 feet in diameter, with skid breaks which do not pass under the wheels but are pressed upon the rails between the wheels, on each side of the engine.

No. CVI.

MASONRY GIRDER BRIDGES.

Design for a Masonry Vaulted Girder Bridge.

To the Editor.

DEAR SIR,—Since writing this paper, I have been informed that a similar construction has been suggested in "Ware on Vaulted Constructions," and that a few bridges have already been built in ribs, and the intervening space bridged over with slabs of stone. I do not think though that they are generally known, or that a comparison has ever been drawn between them and ordinary built bridges.

Your's truly,
F. D. M. B.

THE price of constructing vaults is much reduced by building them with solid ribs and filling in the intermediate space in a less substantial manner. Arched roofing, too, connected by tie-rods is now a common practice, making a strong and permanent flooring for factories, mills, and other large buildings. I propose to apply these two principles to masonry bridges, in the following way, which, as will be seen by the Table at the end, causes the saving of a large percentage of the cost.

The method is to build a masonry bridge as at present, but leaving out so many feet on each side of its axis (or in other words, building two arched masonry girders) and vaulting in the intervening space with a thinner arch. The springing of this cross arch will be kept in a horizontal line by building an abutment for it on the inner sides of the spandrils of the main arches, or girders.

Four designs have been worked out.

No. I. Is with the cross arch 18 inches thick at crown, and 27 inches at the haunches; all the dimensions being calculated to stand the thrust of the cross arch. Tie-rods are added besides to stand half this horizontal thrust (Plate XXII).

No. 2. Is the same as No. 1, except that the cross arch is made 12 inches thick at crown and 18 inches at the haunches; and the other parts calculated in proportion.

No. 3. Has three main arches, with two small cross arches (12 inches thick at crown and 18 inches at haunches) connecting them. The parts being calculated sufficiently strong (as in No. 1), and tie-rods added to stand half the horizontal thrust (Plate XXIII).

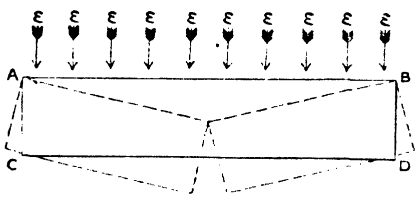
No. 4. Has the space of the cross arch carried to its utmost limit, and the whole thrust borne by the tie-rods (Plate XXIV).

These four designs are compared with an ordinary bridge of like dimensions (Plate XXV).

Design, No. 1.—Span, 55 feet; height of springing above ground level, 13·14 feet; width of arch, $32\frac{1}{2}$ feet; width of roadway, $29\frac{1}{2}$ feet, arch, a segment of 60°; thickness at crown = $3\frac{1}{2}$ bricks = $31\frac{1}{2}$ inches; thickness at haunches = $5\frac{1}{2}$ bricks = $49\frac{1}{2}$ inches; thickness of piers, 7 feet.

Calculations.

Fig. 1.



Suppose ABCD to be a plan of one of the main arches, and AC, BD, its abutments; with the cross arch *e*, *e*, &c. (as shown by the arrows pressing against it). The main arch could only give way

1. By breaking in the centre, like a beam.
2. By the backing being pushed off the extrados of the main arch.
3. By the backing, main arches, and piers, being forced outwards and revolving about the outside edge of the bottom of the piers.

Investigation of No. 1 *(a)*.—ABCD (Fig. 1.) may be supposed to be a beam uniformly loaded and applicable to the formulæ $T = \frac{W L}{8 D}$

where T = the thrust of compression or tension,

W = whole horizontal thrust of cross arch pressing against it.

MASONRY GIRDER BRIDGE.

Fig I.

Elevation. *Section on A.B.*

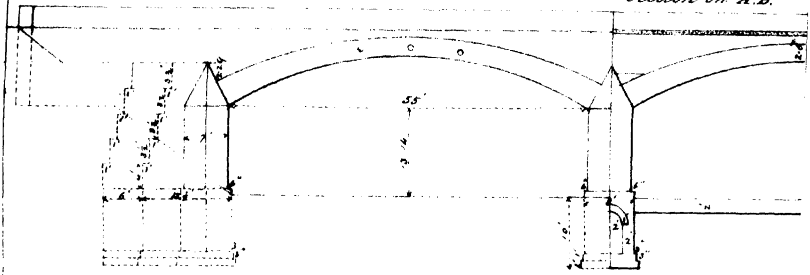


Fig. II.

PLAN.

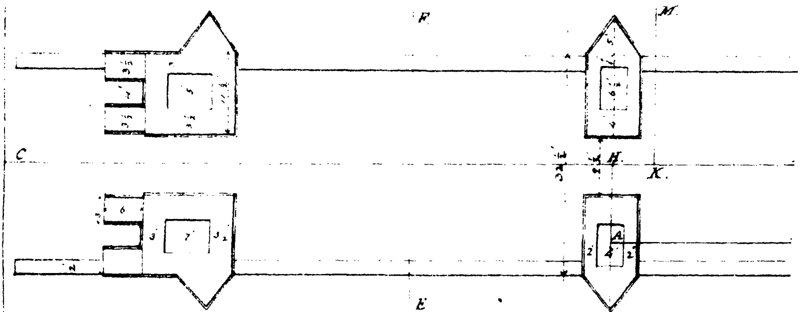


Fig. III

Section on C.D.

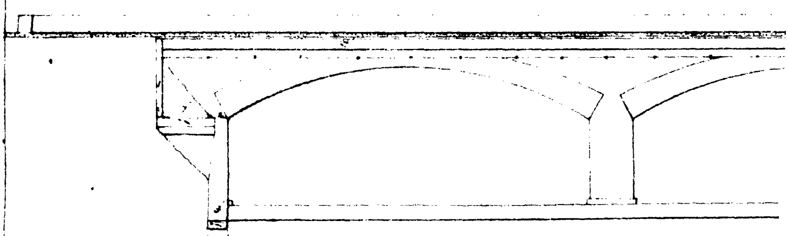


Fig. IV.

Section on E.F.

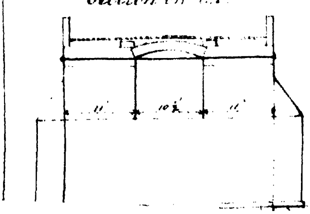
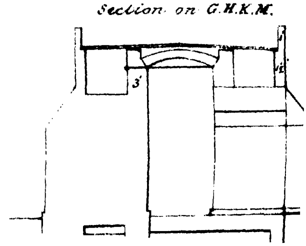


Fig. V.

Section on G.H.K.M.



L = length W acts upon,
D = width of each main arch.

Then, if the inner half area of the key-stone of the main arch can stand half the horizontal thrust + T without crushing, and the outer half can stand half horizontal thrust — T without being torn asunder, the arch will not break.

Supposing the main arches to be 11 feet wide each, the cross arch will be $10\frac{1}{2}$ feet span. Applying the figures for such an arch to the above formula—

$$T = \frac{(3280 \times 62) \times 62}{8 \times 11.} = 143{,}299 \text{ lbs.}$$

Hence the compression on the inner half of the main arch will be

$$\frac{143299 + \frac{1}{2}\text{ (horizontal thrust of main arch)}}{\frac{1}{2}\text{ (sectional area of key-stone in square inch)}} = 182 \text{ lbs. per square inch.}$$

On the outer side, T being tension, the strain of compression will be

$$\frac{235352 - 143299}{66 \times 31 \cdot 5} = 44 \text{ lbs. per square inch.}$$

∴ 11 feet width of main arch will be amply strong.

Investigation No. 1 (b).—If the arch should give way by breaking in the centre, it will revolve about the outer edge of its abutments CD (Fig 1.)

Let H = the horizontal thrust of main arch.

h = sum of horizontal thrust of cross arch acting on the main arch, then $\frac{h}{2}$ = this thrust applied at the centre, of which $\frac{h}{4}$ is supported by each abutment.

L = span of main arch in feet.

W = width of main arch in feet.

1000 W = cohesion of mortar joints (in lbs.) to resist tearing asunder. This acts with a leverage $\frac{W}{2}$ at the abutments, and $\frac{W}{4}$ at the crown (as half of this force at the crown acts on both sides).

Then taking moments about C or D,

$$1000\,\frac{W^2}{2} + 1000\,\frac{W^2}{4} + \frac{H.W}{2} = \frac{h}{4}\cdot\frac{L}{2}$$

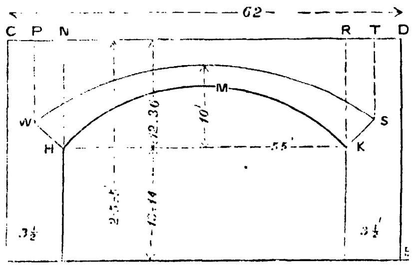
$$W = \cdot 99 \text{ feet.}$$

But the width of main arch is 11 feet.

Investigation of No. 2.—Taking 4000 lbs. per square foot as the strength of good mortar to resist detrusion, and the horizontal thrust of cross arch = 3280 lbs. per foot run ;—

Then $\frac{3280}{4000}$ = 0·8 feet, so that the backing will not be forced off the extrados.

Fig. 2.



Investigation of No. 3.— The weight of the area enclosed within the rectangle ABCD (Fig. 2) may be taken as the abutments to the cross arch, when AE, FB = half width of each pier = 3½ feet.

Then the weight of this area (taking a cubic foot of masonry to weigh 100 lbs.) will be (ABCD — EHMKF) × W × 100 + (moving load and parapet)* + (the roadway) = 57962 × W.

The horizontal thrust of the cross arches acting with a leverage of 21·19 feet = 3280½ × 62 × 21·19; and half the weight of the cross arches (with 100 lbs. per superficial foot of moving load) resting on the main arches = 1894 × 62 = 117,428 lbs.

Then taking moments about the outer edge of the bottom of piers, and letting W stand for the required width of main arches, and 1000 W for the cohesion of the mortar joints (as before)

$$57962 \times \frac{W^2}{2} + 500\ W^2 \times \frac{7}{62} + 117428 \times W$$

$$= 4309869$$

$W = 10{\cdot}33$ feet = requisite width of main arches. Hence 11 feet will be amply wide.

This width of main arches does not increase proportionally with the span of the cross arch. Thus with a cross arch 12½ feet span, W equals 11·05 feet, and with the cross arch 14½ feet span, W equals 11·63 feet, so that the saving of masonry would be much greater as the width of the roadway increased.

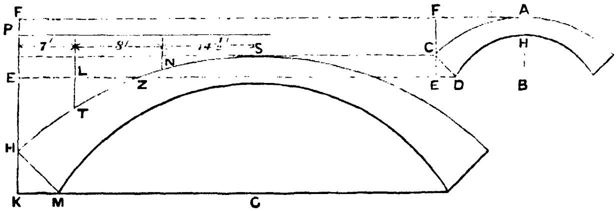
The above dimensions having been proved sufficiently strong (viz., 11

* The moving load has been taken everywhere at 100 lbs. per superficial foot.

feet width of main arches, and $10\frac{1}{2}$ feet span of cross arch) the remaining parts of the construction are as follows:—

Construction of Spandrils.—The backing of the main arch will consist of two walls built flush with its faces: the outer (or real face wall to bridge) will be $1\frac{1}{2}$ feet thick, and the thickness of the inner (or abutment wall to cross arch) will be regulated by the height between the extrados of main arch and springing of cross arch. The space between to be filled with well rammed earth, gravel, or other heavy material. The thrust of the cross arches is also lessened by tie-rods, which are calculated to sustain half the horizontal thrust.

Fig. 3.



$$
\begin{aligned}
KH &= 3{\cdot}57 \text{ feet} \\
HE &= 4{\cdot}48 \;\;" \\
CE &= 1{\cdot}95 \;\;"
\end{aligned}
$$

$$CF = \left\{ \begin{aligned} CP &= 0{\cdot}63 \\ PF &= 0{\cdot}33 \end{aligned} \right\} = \text{height of abutment wall to cross arches above the crown of main arch.}$$

$$\left. \begin{aligned} KM &= 2{\cdot}06 \\ MG &= 27{\cdot}5 \end{aligned} \right\} = 29{\cdot}56$$

$$
\begin{aligned}
AB &= 2{\cdot}94 \\
BH &= 1{\cdot}44
\end{aligned}
$$

To find the thickness of abutment wall to cross arches between E,L.

The greatest height of wall is HP = 7 feet, and greatest leverage of cross arch is HE = 4·5 feet Let B = the required thickness.

$$\text{Then } 7 \times \frac{B^2}{2} + 500\,B^2 + 1894 \times B = 3280 \times 4{\cdot}5$$

$$B = 3{\cdot}2 \text{ feet.}$$

As the leverage HE is continually decreasing, and tie-rods are added, 3 feet may be taken as the thickness of this wall between E,L.

Again, to find the thickness of wall between L,N, where LT = 2 feet; in the same way B = 1·86 feet.

∴ thickness of wall between L,Z = 2 feet.

At the point N the springing point (D) of cross arch will be 4 inches below the extrados of the main arch (*i. e.*, NZ = 4 inches).

∴ from N to S ($14\frac{1}{2}$ feet) $1\frac{1}{2}$ feet will be amply wide for this inner wall (made thicker, if necessary, at N and thinner at S).

Calculation for Tie-rods.—The safe working tension usually allowed on wrought-iron is 5 tons (11,200 lbs.) on the square inch. The total horizontal thrust of cross arches = 3280 × 62 = 203,391 lbs. The bars are required to bear half this thrust. Let there be eight bars.

Then

$$\frac{203391}{2 \times 8 \times 11200} = 1{\cdot}134 \text{ square inches} = \text{sectional area of each bar.}$$

Hence eight bars, $1\frac{1}{4}$ inches diameter (area = 1·227 inches) will be strong enough. These will be placed, one through the centre of main arch, and the rest about $7\frac{1}{2}$ feet apart; the three centre bars passing through the main arches, and the others connecting the cross abutments.

Horizontal Thrust of Main Arches.—Total area of HNRKM (Fig. 2.) = 24·39 × 55 − 997·04 = 344·41

∴ Total weight borne by each abutment, including 100 lbs. per superficial foot, for moving load, $= \frac{(34441 + 5500) \times 11 + 1894 \times 55}{2} = 271{,}760$ lbs., and 271760 × cot 30° = 470,703 lbs. = horizontal thrust. Width of abutment = 11 feet = W.

Height of abutment = 19 feet (*i. e.*, 2·29 feet above H., Fig. 3.) = H.

Let B = required breadth of abutment.

Then

$$\frac{100.H.W.B^2}{2} + 500.W.B^2 + 271760.B$$

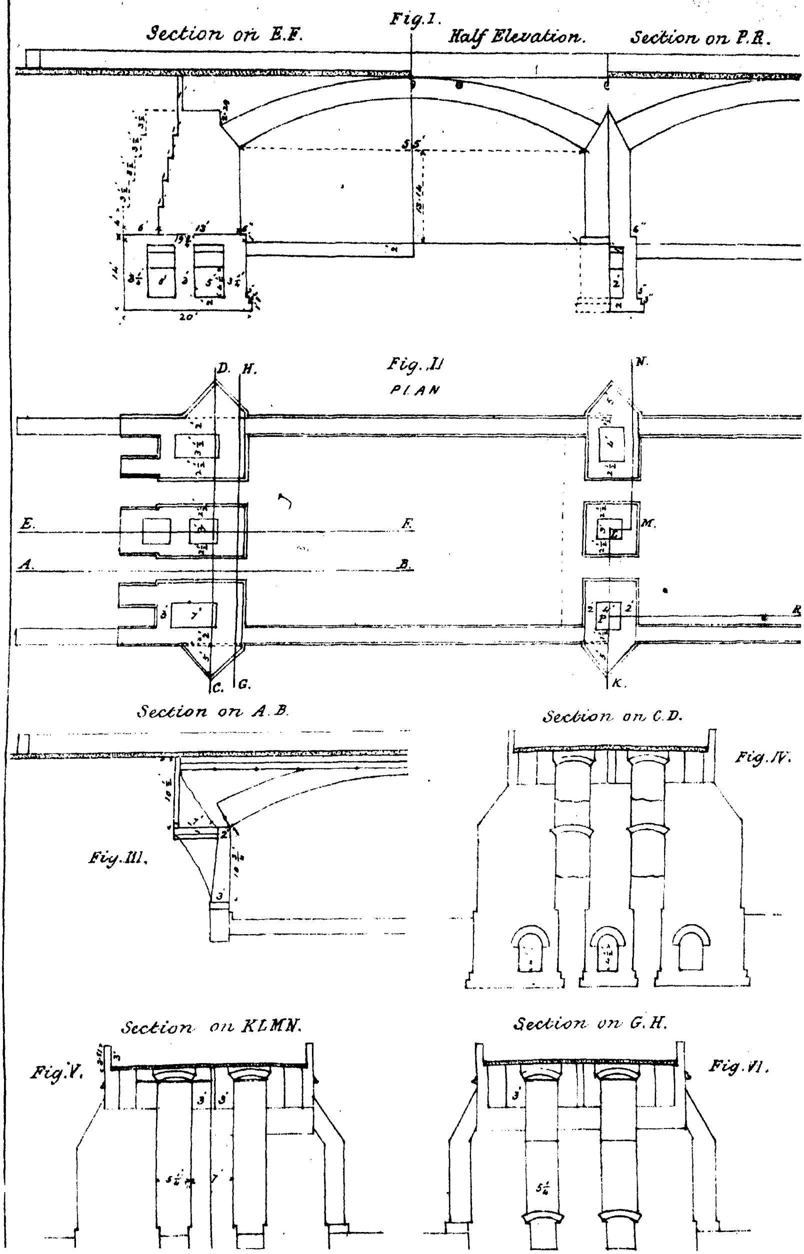
$$= 470703 \times 13{\cdot}14 \quad B = 12{\cdot}94 \text{ feet.}$$

so that 13 feet broad with two buttresses 6 feet long and $3\frac{1}{2}$ feet wide, with both abutments and buttresses cut away in steps for 4 feet, will be sufficiently strong. (*See* Plate XXII.)

The arches between the main abutments, and resting on them, with the walls, &c., which they support (Plate XXII., Fig. III.) will also add to the stability of the abutments.

A revetment wall between the abutments, 23 feet high, to resist the pressure of the earth, would require to be 13 broad at the base, and 8 or 9 feet at the top. This would be an enormous waste of masonry; so I propose to throw an arch across, half way up between the abutments, and let

MASONRY GIRDER BRIDGE.



the earth lie on and under it at its natural slope (as in vaulted revetments in fortifications. Plate XXII. Fig. III.) A revetment wall (resting on an arch between the abutments) to be built to a little above water level and made strong enough to resist the pressure of the water: also a thin revetment wall resting on the inner end of the upper arch, which, having earth on both sides of it, would be subject to little or no pressure, but would prevent the roadway falling in at its junction with the cross roadway arch.

Thickness of Revetment Wall.—Supposing 10 feet of water flowing under the bridge; the revetment wall 13·14 feet high, and B = the required breadth. Then

$$10 \times 62{\cdot}5 \times 5 = 13{\cdot}14 \times \frac{B^2}{2} \times 100. \quad \therefore B = 2{\cdot}14.$$

∴ 3 feet at base and 2 feet at the top will be strong enough, especially as it has a good deal of lateral support as well.

Design, No. 2.—18 inches thick at the crown and 27 inches at the haunches, may be rather too strong for an arch of only $10\frac{1}{2}$ feet span. By making the cross arch 12 inches thick at the crown, and 18 inches at the springing, the dimensions of the main arch is slightly reduced. Thus—

Width of main arches 10·5 feet,
Span of cross arch 11·5 „
CF (Fig. 3) = 1·24 „

Weight of half cross arch with moving load = 1709 lbs. per foot run; horizontal thrust of ditto = 2960 lbs. per foot run.

Width of Main Arch.—Working out the thrust of cross arches (as in page 4, except the average of cross arch = 21·84 instead of 21·19) the width of each main arch = 9·74 feet.

∴ 10·57 feet will be strong enough.

Total area of HNRKM (Fig. 2) = 24·71 × 55 − 997·04 = 362·01.

∴ Total weight borne by each abutment, including 100 lbs. per superficial foot for the moving load $= \frac{(36201 + 5500) \times 10{\cdot}5 + 1709 \times 55}{2} =$ 265,928 lbs.

Horizontal Thrust of Main Arches.—And horizontal thrust = 265928 × cot 30° = 460601 lbs.

Width of abutment = 10·5 feet = W
Height of abutment = 19 „ = H

Let B = the required breadth of abutment $\frac{100.H.W.B^2}{2} + 500\ B^2 + 265928.W = 460601 \times 13{\cdot}14$

$\therefore$ B = 13·03 feet.*

Tie-rods.—With the exception of the change in dimensions herein given, the construction is the same as in Design, No. 1.

There are to be eight rods, as in No. 1, the dimensions of each rod will be $\frac{2960 \times 62}{2 \times 8 \times 11200} = 1{\cdot}024$ square inches.

$\therefore$ diameter of each tension rod = $1\frac{1}{4}$ inch (area = 1·23 square inches).

DESIGN, No. 3.—Plate XXIII. Is to have three main arches and two cross arches.

Suppose each outer main arch $7\frac{1}{2}$ feet wide, and centre main arch 7 feet wide.

Then each cross arch will be $5\frac{1}{4}$ feet span; the thickness at crown, 12 inches; at springing 18 inches.

Rise of cross arch 0·7 feet.

CF (Fig. 3) = 0·4 feet.

Weight of half cross arch with moving load = 759 lbs. per foot run.

Horizontal thrust of ditto = 1314 lbs. per foot run.

Width of Outer Main Arches.—Then working out the thrust of cross arches (as in page 154), but taking 21·84 feet as the leverage of the cross arches instead of 21·19 feet, the width of each outer main arch will be 7·26 feet.

$\therefore$ 7·5 feet will be strong enough.

Horizontal Thrust of Outer Main Arches.—Total area of HNRKM (Fig. 2) = 23·87 × 55 − 997·04 = 315·81.

$\therefore$ total weight borne by each outer abutment, including moving load = $\frac{(31581 + 5500)\ 7{\cdot}5 + 757 \times 55}{2}$ = 159,926 lbs., and 159,926 × cot 30° = 276,999 lbs. = horizontal thrust.

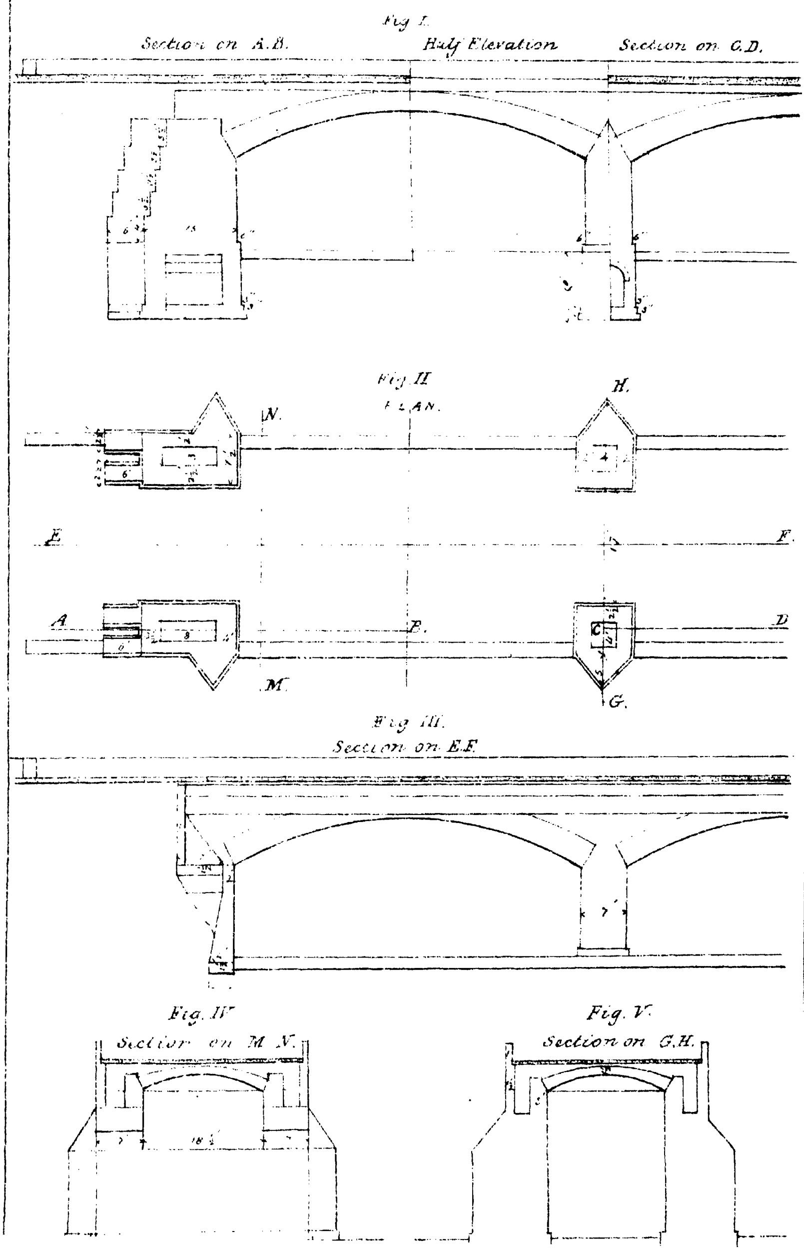
Width of abutment = 7·5 feet = W

Height of abutment = 19 „ = H

* Supposing the whole weight of the cross arch to be borne by only the first 3 feet of each main arch, then the horizontal thrust of the main arches for these 3 feet will be $\frac{(36201 + 5500)\ 3 + 1709 \times 55 \times \cot 30^{\circ}}{2}$ = 189,745 lbs.

Hence the pressure per square inch on the key-stone for these 3 feet would be about 167 lbs.

MASONRY GIRDER BRIDGE



Let B = required breadth of main side abutment.

$$\text{Then } \frac{100.\text{H.W.B}^2}{2} + 500.\text{W.B}^2 + 159926.\text{W}.$$

$$= 276999 \times 13{\cdot}14$$

Whence B = 12·37 feet.

Again, half the weight of main centre arch =

$\frac{(31581 + 5500) \times 7 + 757 \times 55 \times 2}{2}$ = 171,528 ℔s., and 171528 × cot 30 = 297,095 ℔s. = horizontal thrust.

$$\text{Then } \frac{100 \times \text{H} \times \text{W.B}^2}{2} + 500\ \text{W.B}^2 + 171528.\text{W}$$

$$= 297095 \times 13{\cdot}14$$

Whence B = 12·9 feet.

Therefore 13 feet may be taken as the breadth of the three abutments with two counterforts to each 6 feet long, those to the side abutments being 2 feet thick, and to the centre 3 feet thick, each. The back arranged in steps (as in Plate XXIII., Fig. I.) The remaining details as laid down in Design, No. 1, or as shown in the sections, Plate XXIII.

Crushing Weight on Key-stone.—Crushing weight per square inch on key-stone of main centre arch $= \frac{\text{horizontal thrust}}{\text{sectional area in inches}}$ = 112·28 ℔s. per square inch.

Tie-rods.—There are to be eight tie-rods to bear half the horizontal thrust of main arches.

$\therefore \frac{1314{\cdot}63 \times 62}{2 \times 8 \times 11200}$ = 0·4549 square inches = sectional area of each bar.

∴ diameter of each tension rod = $\frac{7}{8}$ inch (area = 0·6 square inch).

Abutment Walls to Cross Arches.—The abutment walls to the cross arches will be of same thickness as in Design, No. 1.

Design, No. 4. Plate XXIV.—Is the same in construction as No. 1, except that the whole thrust of the cross arch is borne by the tie-rods; the main arch only being made strong enough not to twist or crush. The whole thrust of the cross arch being borne by the tie rods, there will be no use in investigating whether the main arches would break in the centre as there is no outward thrust on them.

Suppose the main arches 7 feet wide.

Then span of cross arch = 18½ feet; thickness at crown, 18 inches; at haunches, 27 inches; rise of cross arch = 2·03 feet.

$$CF \text{ (Fig 3)} = 2{\cdot}03 \text{ feet.}$$

Weight of half cross arch with moving load, &c., 4326 lbs. per foot run.

Horizontal thrust of ditto = 7493 lbs. per foot run.

Tie-rods.—Total horizontal thrust of cross arch in 62 feet, divided amongst thirteen tie-rods, gives a sectional area of

$$\frac{7493 \times 62}{13 \times 11200} = 3{\cdot}19 \text{ square inches to each rod.}$$

Diameter of each rod = 2 inches (area = 3·14 square inches).

Expansion of ties.—The expansion of wrought-iron between 30° and 212° is ·0012 of its length.

∴ The greatest expansion that could take place between those extremes of temperature would be ·0012 × 32·5 = ·039 feet = 0·468 inches. But as the greatest extreme (supposing the ties to have been originally put up at a mean temperature) will never exceed 50°, the expansion or contraction of the bars will be unappreciable.

Horizontal Thrust.—Total area of HNRKM (Fig. 2) = 25·67 × 55 − 997·04 = 414·81 square feet.

∴ total weight of each abutment and moving load =

$$\frac{(41481 + 5500)\,7 + 4326 \times 55}{2} = 283{,}398 \text{ lbs.}$$

and 283398 × cot 30° = 490860 lbs. = horizontal thrust.

Width of abutment = 7 feet = W

Height of abutment = 19 ,, = H.

B = required breadth.

$$\text{Then } \frac{100.H.W.B^2}{2} + 500.W.B^2 + 283398 \times W$$
$$= 490860 \times 13{\cdot}14$$

Whence B = 14·86 feet.

Therefore 15 feet will be the breadth of the abutments (arranged in steps at the back, as in Plate XXIV.) with two counterforts to each abutment, 6 feet long and $2\frac{1}{2}$ feet wide.

Crushing Weight at Key-stone.—The crushing weight at key-stone of main arch $= \frac{\text{Horizontal thrust}}{\text{Sectional area in inches}} = 184$ lbs. per square inch.

The crushing weight of brick-work is 1,500 lbs. per square inch.

Calculations for the dimensions of an ordinary bridge of the same span, &c. Plate XXV.

MASONRY GIRDER BRIDGE.

Fig. I.

Elevation.

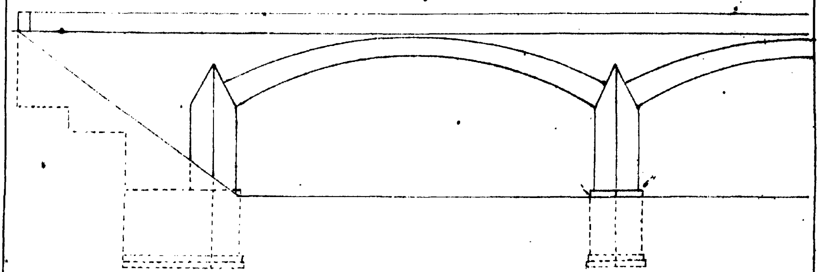


Fig. II.

PLAN.

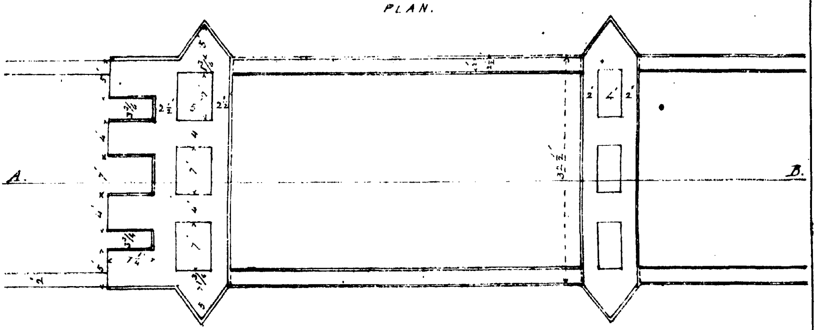
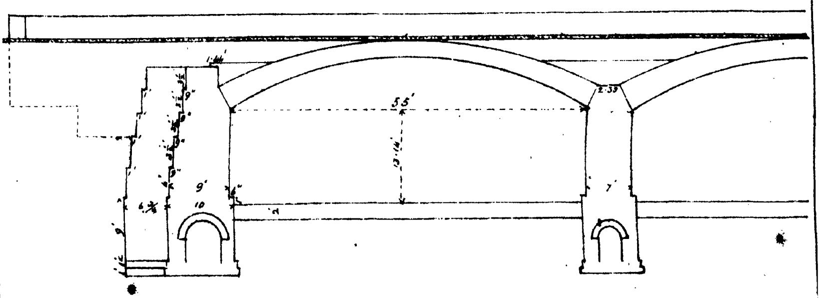


Fig. III.

Section on A.B.



Scale, 4" = 100 feet.

Total area of HNRKM (Fig. 2) = $23 \cdot 64 \times 55 - 997 \cdot 04 = 303 \cdot 16$. Total weight per foot borne by each abutment with moving load = $\frac{30316 + 5500}{2} = 17,908$ lbs.

$$\text{and } 17,908 \times \cot 30^\circ = 31018 \text{ lbs.} = \text{horizontal thrust.}$$

$$\text{Height of abutment} = 19 \text{ feet} = H$$

$$B = \text{required breadth.}$$

$$\text{Then } \frac{HB^2}{2} + 500\, B^2 + 17908 \times B = 31018 \times 13 \cdot 14$$

$$B = 7 \cdot 52 \text{ feet.}$$

Let the abutments be 9 feet broad with four counterforts 7 feet long, the two inner ones 4 feet wide and two outer 5 feet wide, and reduced at the back as shown in Plate XXV., Fig. III.

The face walls to be $1\frac{1}{2}$ feet thick, and the remaining dimensions as shown in Plate XXV.

REMARKS.—In a small bridge of three bays, there is a saving of from 7 to 10 per cent; but in a large bridge requiring (say) 1,925 feet waterway, or thirty-five such bays, and having five abutment piers, the comparative cost of a bridge of ordinary construction, and of the four Designs given, would be as follows:—

	Total cost of bridge.			Per Centage.	
	Rs.	A.	P.	Gain.	Loss.
Bridge of comparison, ...	1,99,255	13	3	...	...
Design, No. 1, ...	1,80,090	4	9	9·62	...
„ „ 2, ...	1,74,328	14	9	12·51	...
„ „ 3, ...	1,79,170	13	6	10·08	...
„ „ 4, ...	1,79,184	12	9	10·07	...

But in such a bridge the curtain walls would be of a more expensive construction, which would decrease the percentage. The foundations, on the other hand, being also more expensive, would raise the percentage, so that a saving of 10 per cent. may be taken as a fair average. The above figures show that, *cæteris paribus*, a long bridge gives a greater percentage of saving than a short one, and in page 154, it has been shown that the wider the bridge, the cheaper (proportionally) such a construction would be. The Hexagonal Syrian Tiles (the construction of which, by Col. Fife, was published in Vol. I. of the Professional Papers on Indian Engineering) would make a capital material for the cross arches. In England small arches, up to 25 feet span have been constructed of a single ring 6 inches thick of corrugated clay pipes, and found to stand the passage of heavily laden waggons without being in the least injured.

For second class bridges, I propose building two main arches (as in Design, No. 4) with the inner face walls (called in previous Designs, abutment walls to cross arch) made thick enough to stand the pressure of the backing, and built to a level with the top of the crown of the main arches. On these walls will rest wooden beams bridging over the intervening space, and on these beams will be laid the roadway, as in ordinary iron or timber bridges. The width of the main arches will depend on the span. Such a roadway between the main arches would add so little to their weight (and consequently thrust) that the abutments would be comparatively small. The saving in the cost of such a construction would be much greater than in the above Designs, and the bridge can be made as permanent as required.

The advantages in the Designs given are—

1. There is a large saving in expense.
2. Should workmen be scarce and the stream to be bridged subject to freshets likely to carry away the centerings and destroy the unfinished superstructure; only one main arch (or less than one-third of an ordinary bridge) need be built at a time, when the damage done would be considerably less, and might often be avoided altogether.
3. The amount of material to be collected and the number of laborers would be greatly reduced. The iron work being of the simplest description can be done by ordinary native blacksmiths.
4. In deep well foundations the percentage of saving would be enormously increased.

F. D. M. B.

Note by Editor.

I doubt whether in ordinary cases, the 10 per cent. saved would not be

Tabular Statement showing the relative cost of the different Constructions.

Cubic contents, and cost of one Abutment.

Foundations.						Superstructure.																		Remarks.	Total cost of one Abutment.
Masonry.				Percentage		Masonry.				Cross arch masonry.				Iron bars.				Total.			Percentage.				
C. ft.	R.	A.	P.	Gain.	Loss.	C. ft.	R.	A.	P.	C. ft.	R.	A.	P.	lbs.	R.	A.	P.	R.	A.	P.	Gain.	Loss.			

... Main arch,	3,695	1,182	6	6	1,869	13	3	31·89	...	1,635	310	10	6	4,200	630	0	0	872	69	12	3	3,810	15	3	9	1,025	10	6	...	205·97	2,895	7	9
Cross arch,	2,546	687	6	9																													

...oring of one Bay.

	Masonry.			
	C. ft.	R.	A.	P.
...on,	4,428	1,107	0	0
...	4,428	1,107	0	0
...	4,428	1,107	0	0
...	4,428	1,107	0	0
...	4,428	1,107	0	0

Comparative Total Cost of a Bridge of three Bays.

	Total cost of foundations.			Percentage.		Total cost of superstructure (without flooring)			Percentage.		Total cost of Bridge including flooring.			Percentage.		Remarks.
	R.	A.	P.	Gain.	Loss.	R.	A.	P.	Gain.	Loss.	R.	A.	P.	Gain.	Loss	
Bridge of comparison,	2,992	2	0	...	...	13,549	10	6	...	...	19,862	12	6	...	...	
Design, No. 1, ...	2,615	9	6	12·60	...	12,472	7	6	7·94	...	18,409	1	0	7·32	...	
„ No. 2, ...	2,552	14	6	14 71	...	12,018	2	3	11·30	...	17,892	0	9	9·93	...	
„ No. 3, ...	2,771	5	6	7·39	...	12,246	12	3	9·62	...	18,339	1	9	7·67	...	
„ No. 4, ...	2,058	12	0	31·22	...	12,730	15	3	6·04	...	18,110	11	3	8·83	...	

...h masonry, including centerings, Rs. 32 per 100 cubic feet.
...h masonry do., up to 18½ span, Rs. 27 „ „
...Ditto, do., up to 16½ „ Rs. 26 „ „
..., including nuts and workmanship, Rs. 12 per maund.

Brick-on-edge flooring, ... Rs. 25 per 100 cubic feet.
Plain masonry, ... Rs. 19 „ „
Kunkur metalling, ... Rs. 8 „ „
Earthwork ... ... Rs. 4 per 1000 cubic feet.

counterbalanced by the more complicated construction proposed. But the fourth advantage claimed, where expensive foundations are employed, appears deserving of much consideration. Supposing, for example, in a railway bridge with 100 feet spans, that the masonry piers supported on deep well foundations were so far modified, that the centre portion of the pier, instead of being continuous, were replaced by an iron girder carried on the two end portions. This cross girder would carry the two inner longitudinal girders (or two inner rails, in the case of a double line), the two outer girders being carried on the masonry ends of the piers. Such a girder would have a length (or bearing) of (say) 16 feet, a depth of 18 inches, and would have to carry a distributed load of 100 tons, for which a section of 30 square inches for either flange would be amply strong; while the cost of this short girder would be very much less than the portion of the masonry pier which it replaced, and the extra wells required for its foundation. This of course has nothing to do with the above calculations so far as arches are employed, and is simply another form of open piers, as when hollow cast-iron tubes are used, for instance. But it might be employed where iron cylinders or screw piles could not be procured; while the iron girders, if not procurable, might be replaced by timber.

No. CVIII.

PRESBYTERIAN CHURCH—ALLAHABAD.

THE architecture of this building is of the simplest early English with very little ornament, effect being mainly sought by contrast of material and workmanship employed.

The mass of the masonry is of brickwork, pointed on the exterior and plastered interiorly, but all the openings, buttresses and quoins, have stone dressings; and the copings, cornices and pinnacles, are also of stone.

The building consists of a nave and side aisles; the interior walls on either side being pierced by large Gothic arches with deep mouldings springing from stone columns, each of which consists of four cylindrical columns clustered into one.

The principal entrance is through a doorway entirely of stone, with deep mouldings and detached columns in the side jambs, under a carriage porch of coursed rubble stone, the exterior having the face pitched, and the interior dressed to a fairly smooth surface.

There is an entrance at either side into the body of the Church, through a high Gothic doorway, with attached columns of stone in the side jambs, and towards the south end of the Church further from the main entrance on either side, a small porch is attached; one of which forms a vestry, the other an entrance.

The Church ranges north and south. The main entrance is to the north, and the southern end is occupied by a large window of three lights, the jambs and mullions of which are all of stone.

There is a circular window of stone tracery high in the northern gable.

The floor is flagged with stone slabs 18 inches square, alternately white and red in color; the roof covering is of corrugated galvanized iron laid on and bolted to purlins fixed to the principals of the trusses.

The pitch is high, the vertical angle 80°. The trusses of sál wood; hammer and collar beam, the exposed portion being worked into deep mouldings and varnished.

A ceiling of American pine planking, tongued and beaded, and varnished, is laid under the principals and collar beams of the trusses. The contrast of color between the dark sál wood and light colored pine produces a pleasant effect.

The hammer trusses run down and terminate on corbels of stone, somewhat similar in form to the large columns of the nave.

The doors and windows are all of teak wood varnished. Chandeliers, wall and pulpit lights of appropriate design in bronze, have been procured from London.

The sittings, when complete, will consist of arm chairs of a simple pattern, ranged within book rails of teak wood, with heavy standard ends to form pews.

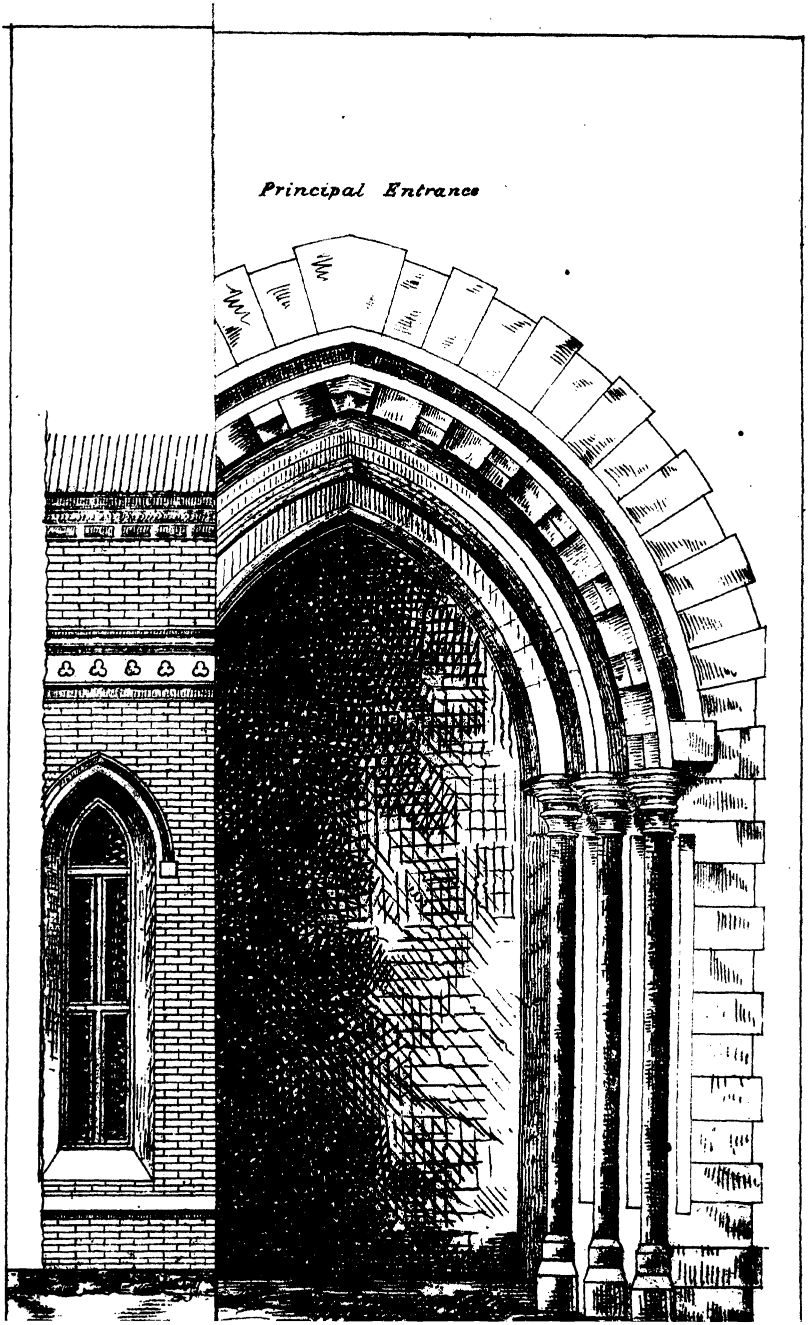
The cost has been defrayed in about equal proportions by the Government and the congregation, who hope hereafter to raise funds sufficient to add a tower and spire.

F. W. P.

[This Church was built by Capt. D. Limond, R.E., from the designs of Capt. Peile, R.E., Superintending Engineer.—Ed.]

PRESBYTERIAN CHURCH.—ALLAHABAD.

PLATE XXV


Principal Entrance

No. CIX.

RAILWAYS IN WAR.

In whatever degree existing Railways may affect the operations and movements of troops in future warfare, it is undoubtedly extremely important that an army occupying a civilized country should contain amongst its numbers, a small body of men conversant at least with the elementary principles of Railway construction. For, by being familiar with the duty of each part in any structure, we know where to attack it in order to destroy or disable the same according to the exigencies of the case.

In the present paper it is proposed to consider as briefly as possible, in what manner and by what means, a line of Railway may in time of war be dismantled, in order to impede or arrest the enemy's trains; and on the other hand, how the damage done by the enemy may be most expeditiously remedied with available resources. The following remarks, although intended for a Railway constructed with rails supported at intervals in chairs on wooden cross sleepers, (such as the London and N. W. Railway,) will be found applicable with modification, to lines with various superstructures of any gauge.

To proceed then at once to consider the different ways in which such a line of communication may be destroyed or rather broken in the field, so as to interrupt the passage of trains, it is proposed to class them under seven heads, the selection from which will depend on existing circumstances. The passage of trains may be interrupted :—

1. By removal of keys and widening of gauge.
2. By displacement of rails with or without destruction of chairs.
3. By displacement of rails and destruction of sleepers.
4. By abduction of rails, chairs, and spikes, with destruction of sleepers.

5. By blowing in the sides of deep cuttings.
6. By the demolition of some permanent structure such as a bridge or viaduct.
7. By blowing in tunnels.

In the first process about a quarter of a mile of line could be disabled by 20 men provided with suitable hammers in half an hour, and the keys burnt or otherwise made away with. The effect would be, that any train travelling along the line would leave the track and considerable damage ensue, unless the driver perceived the alteration of guage and pulled up in time, which is extremely unlikely; and even in that case, although there would be no more damage than the loss of keys, considerable delay would be the result.

Process No. 2 would require more time, trouble, and additional tools, for should the rails be fished, wrenches as well as heavy hammers,* will be requisite. With these tools, the rails may be abstracted (leaving the chairs on the sleepers) and buried, thrown into a river if convenient, or concealed by other means, as probably it will only be desirous to break up a short length this way. Twenty expert men could certainly complete it in half an hour or less, exclusive of the time employed in making away with the metals.

Process No. 3 will require additional tools, in the shape of shovels and picks for the removal of the ballast, in order to displace the sleepers. It would seldom if ever be advisable to remove the chairs from the sleepers, as the operation is too laborious; for the spikes having rusted, hold with remarkable pertinacity in sound wood, and it is only by continued blows from a heavy hammer that they can be extracted.

By processs No. 4, the whole of the permanent way is removed and concealed or destroyed; it must be only on peculiar occasions that this is expedient, as the trouble and time expended would not receive adequate compensation from this entire demolition of permanent way.

By process No. 5, an obstruction in the shape of earth is merely placed on the road and little or no material damage done to the Railway, but a delay occasioned in proportion to the quantity thrown down and the means available for its removal.

The amount of destruction caused by process No. 6, must be regulated

* Ordinary plate-layer's hammer.

according to circumstances. The bridge may be entirely demolished, or only one arch; or one pier of a viaduct blown down.

When process No. 7 is resorted to, the point of attack must be well chosen; it will vary with the length of the tunnel, and the nature of the rock, (in a geological sense,) through which it passes. Long tunnels through hard solid rocks, such as require no lining, will be best attacked at the shafts by blasting from the top, or by other means of filling in. Short tunnels with masonry lining may be advantageously attacked at the crown or both haunches.

Whenever it is determined to interrupt the passage of trains, of course the desired end should be sought for, with the least trouble, expense, and permanent damage. As expressed by General Sir J. Burgoyne, "in damaging a railway to impede the progress and available means of an enemy's army, the object will of course be to do as little injury to a great convenience of the country as is consistent with the primary consideration of crippling the military resources of the enemy for the time." As this paper aims merely at practical facts it will not be out of place to enumerate the tools necessary in the foregoing operations, which may be classed under two heads A and B.

A, including Nos. 1, 2, 3, and 4, are all attacks on the permanent way.

B, including Nos. 5, 6, and 7, are all attacks on permanent structures.

In order to decide upon the number and proportion of tools, it is necessary to take some number of men as a standard unit, or detachment complete, of which there may be any number with an army; and for this purpose it is proposed that a detachment should consist of 22 men, exclusive of non-commissioned officers. For operations under the head A, the detachment will require

8 Picks and shovels for opening up the ballast.
4 Screw spanners to take off fishes.
15 Heavy hammers to force the sleepers from the chairs, and having one end small for keys.
4 Handspikes.

The above numbers are chosen in order that every man many be employed from the first on the most complete demolition. Thus, to commence work, we have eight men with picks and the same number with shovels to remove the ballast, four men with spanners to take off the fishes, and two men with hammers to displace the keys. As previously mentioned, the separation of sleepers and chairs is extremely laborious, and therefore when necessary, the simplest and best way would be to form stacks and burn the sleepers, when the chairs might be afterwards collected.

In operations under the head B, such tools would be required as have hitherto been in use for the demolition of ordinary bridges, &c., on common roads; and as in these, there is nothing new to the Military Engineer, no further comment is here called for on this portion of the subject.

Having thus briefly noticed the several ways in which the Railway may be most readily dismantled, it behoves us to consider the more difficult work of *reconstruction*, and in so doing it will be convenient to preserve the order above adopted, and to suppose that the line has been disabled in one of the manners already described, by process 1, 2, 3, &c., and to note in each case the method peculiar to itself.

When the keys have been made away with, we should naturally replace them by new ones; these may be rough pieces of wood, dressed in proportion to the time and means available.

But should it be impossible to make new keys, from want of timber or any other cause, a sufficient number may be obtained from the *entire* portion of the line, by abstracting one from the centre of each rail (but not both from the same sleeper). It would be well as a precaution to wedge up the rail, where keys were absent, by stones or anything at hand, but this is not absolutely necessary provided that there are not two consecutive keyless chairs.

Of course it will be necessary to limit the speed of passing trains, over these portions in proportion to the want of perfection in the repair.

Should the line have been dismantled by any other process under the head A, the mode of reconstruction will be explained for all, if we take the worst case, in which the whole of the permanent way has disappeared, and show by what means it may be renewed.

Here we have a break in the Railway where nothing remains but the formation level and ballast, and it is necessary to construct a way across this for the passage of trains.

Now, it is very evident that this cannot be done without materials, and thus assuming that there is no depôt within reach, the important question is, where are they to come from? Doubtless on a double line one track can be renewed at the expense of the other, and by this means a through many of them may be clubbed together as may be requisite to form a Number, but no more.

8*th*. When a holding of less area than that required by Rule 1, does not adjoin another similarly circumstanced, it should be made a separate Number.

If therefore it be assumed that one pair of bullocks are able to plough

20	acres of	light dry crop	soil,
15	„	medium	„
12	„	heavy	„
4	„	rice land	„

then the plot of land forming the standard unit or "*Revenue Survey Number*," would be of a size between this amount and its double. By the survey operations the lands of a village are thus cut up into plots of ground of a nearly uniform size; and on the map, the limits of these are defined by continuous black lines, so that something of a gridiron appearance is presented, similar to the skeleton triangulation of a trigonometical survey.

In order to preserve these Numbers intact for revenue purposes after they had been once constituted by the survey, and to prevent their being split up into portions too minute to afford subsistence to the cultivators, it was decided, supplementary to Rule 7 above, that when two or more occupants were included in the same number, and any one of these relinquished his share or died without heirs, the portion must be taken up by one of the other cultivators; or failing that, by some one else. In the event of there being no one ready to cultivate the waste portion, the whole Number must be relinquished. All sales, transfers, &c., of Government land, were directed to be of portions recognized in the Revenue records, which would as a rule be whole Survey Numbers. In agreeing to cultivate waste land, the ryots are required also to take up entire numbers, excepting where the annual assessment exceeds Rs. 20, when the names of two ryots are permitted to be entered.

These arrangements effectually secured the internal integrity of each Survey Number; and the next question that presented itself was—How to ensure the preservation of their external limits or boundaries? Without some external marks easily recognized and of a permanent character, these Numbers would not retain their original form, and after the lapse of a few years the areas would have so altered as to render the assessment unequal and perhaps render a fresh measurement necessary. A continuous ridge or mound of earth encompassing the entire number, is doubtless the best boundary, but it would be too expensive in practice, and a system of detached earthen mounds, two at each of the four corners of the number and one at convenient intervals, say every ten chains along the sides, with stones sunk at the bends, was found on trial to be a sufficient demarcation of the limits of numbers, and this is therefore the system which has been adopted throughout the Bombay Presidency.

All disputes about tenures, occupancy, limits of fields, and other purely Revenue matters, have to be adjusted by the Civil Authorities, whose aid is called in when requisite for that purpose, either by the measurer or by the European Assistant himself. But when these disputes occur between villages concerning their mutual boundaries, they will be found sometimes very troublesome to adjust, more especially when the rights of alienees are affected. Many of these disputes are of long standing, some even tracing so far back as hundreds of years, and concern large tracts of land; several will be found to have been the scene of faction fights, and even in some instances, to have been attended with bloodshed. The existence of these disputes in any number, if not settled at the time of the survey, delays the completion of the records of the villages that are affected by the dispute, and their classification and settlement has to be put off till these can be finished. The Survey operations may in this manner be seriously compromised unless early attention be given to these disputes; and when once settled, no time has to be lost in erecting the boundary marks to prevent their being re-opened.

In the actual settlement of these disputes, the Assistant will soon find that an accurate map of the land in question is an indispensable preliminary to an investigation of the villagers' claims. The disputed land therefore should be surveyed in presence of both parties, and all topographical features and permanent marks noted, such as water-sheds, nullahs, cartroads, and also temples, tanks, wells, fruit trees, trijunction stones or pillars, cultivated land, &c. This latter class of objects is very useful in establishing the right of usufruct or occupancy, and a search amongst the records produced by the villagers will generally confirm the possession to one of the parties. The dispute may thus be generally narrowed to merely the waste land; and failing proof of this, it may be divided into equal parts between the villages, or else some permanent natural boundary, such as a water-course, water-shed, or cartroad, if conveniently located, may be fixed [illegible] the mutual limit. Disputes between Government villages can be decided by the Survey Assistant without much trouble ; but when one of the parties is an alienee, it is advisable to take his written agreement to constitute the Assistant the umpire in the dispute, and to abide by his decision without appeal.

To prevent any after misunderstanding, the exact line of boundary, as finally agreed on, should be traversed in, and permanently marked off by means of masonry pillars. These should be of the same size, and at as long distances apart, as is compatible with being well in sight, the one from the other; all intervening bends and earthern marks being fixed by means of off-sets taken with the cross-staff. These distances are marked in figures on the map, which is made up in duplicate, and signed on oath as correct by the professional measurer; the duplicates are countersigned by the Assistant, and the alienee or his accredited agent, and one copy is retained by each party. It is then nearly impossible that these disputes can be re-opened, and the exact boundary fixed by the Survey can always at any future time be recovered.

The above gives a brief description of the principles on which the Measuring branch of a Survey is conducted. In the actual field operations the European Assistant has usually some twenty Measurers, and three learners of measuring, under him. His duties are to supervise and *test* the work of these men, he making no original surveys himself. It is usual to give the entire of one *talooka* or *mahal* to one establishment, and on receipt of the list of villages therein, at the close of the monsoon, the Assistant appoints measurers to contiguous villages at one end or corner of the district allotted him; and as these are finished, moves on the men gradually towards the other or opposite corner, by surveying the villages *en route* in succession; and by this arrangement, the Assistant can always, without shifting his camp often, be within easy reach of his measurers, and able to pay them those sudden and unexpected visits so necessary to the preservation of the discipline and efficiency of a native establishment. As a general rule, the best measurers should be appointed to the largest villages or towns, more especially those which have much garden or rice land, and so down by gradation; the fresh hands being put to the smallest villages of 3 and 400 acres. It is not advisable to appoint more than one measurer to one village, as if two or three measurers be appointed, the daily duty of attending the measurers in the field, dragging the chain, holding bandrols, erecting boundary marks, &c., would be too onerous for the village officers and inhabitants. If, however, under any peculiar circumstances it becomes necessary to appoint two measurers to a village, it should be divided into two portions, having a road or large nullah as the boundary; this should be carefully traversed in with a theodolite, and the same tracing being given to both, the work of the two is kept perfectly distinct, and the maps made up by the two measurers can be easily joined together. Villages are rarely of such size that they cannot be done single handed by one good measurer in a season, and it is better to appoint trustworthy measurers to the larger villages at the commencement of the working season, even if they are at some distance from the Assistant's camp, rather than wait until the work has arrived in their vicinity, and there appoint two or three measurers thereto.

The survey made by the European Assistant is as above stated, not an original survey, but a test of the Measurers work, and is of the utmost importance; as from its agreement or otherwise within a certain small percentage of the work of the measurer, the entire measurements of the latter are either accepted or rejected. This test should be constant and recurring; and, if the measurers have been appointed to villages in a proper manner, the Assistant's camp can be pitched at some village centrically situated with reference to these, and no difficulty will be experienced in taking a proper number of tests of any village that may be finished during the season. After some amount of practice, when the Assistant can plot his work with a considerable amount of accuracy, he should not allow the measurer to exceed 1 per cent. in error in all numbers above six acres, if not of a very irregular figure; 2 per cent. may be allowed if under six acres; but an error of 3 per cent. ought never to occur, except in very small garden or rice Numbers.

The only part of the measuring operations remaining to be noticed, are the arrangements of the native measurer. The chain with which the areas of numbers are ascertained is 33 feet in length, exactly half the length of Gunter's chain, and is divided into 16 links, called *annas*, of 2 feet $\frac{3}{4}$ inch each. Forty of these square chains make an acre, and a square chain is equal to 4 poles, or $\frac{1}{40}$th of an acre, and is called a "*goonta*," the areas being calculated in acres and "goontas." The measurer is provided with a wooden staff or gauge 8 feet 3 inches in length, for the purpose of constantly testing his chain; he is supplied also with a pair of compasses and a diagonal scale showing chains and annas. His map is constructed to a scale of 8 or 16 inches to the mile, according to the average size of the Survey Numbers, whether large or small.

In the example herewith given of a measurer's map, is shown the method of the division of land into Revenue Survey Numbers, the method of setting up the boundary marks in the field, and the plotting of the map itself on the base lines. This latter should invariably be effected by the principle of the triangle and not the right angle, for which the measurer is supplied with no instruments. The areas in the measurer's map are intended merely as a guide for the terminating points of other lines, and should be described faintly with the steel compasses. The diagonal with off-sets, is as a rule, the system adopted in the field measurement. The measurer devotes one day every week or every fortnight to an inspection of boundary marks, and sees to the payment of the laborers who have erected them.

After the measurers have obtained some experience in mapping, there is found to be no difficulty in piecing together these Survey Numbers, one next another, so as to form an entire map of a village. A great assistance is however given to the correct protraction of the map, by means of lines ranged from one boundary of the village to the opposite one, and all the first Survey Numbers are measured along this; in measuring the subsequent ones, it is as well to return to the base line numbers, every now and then, so as to keep up a constant check on the accuracy of the protraction. For a village of 1000 acres, one base line will be found to be sufficient, if properly selected in a locality free from jungle and other obstacles, and two base lines will be enough for a village up to 2,000 acres. These base lines are connected with one another by means of a triangle, as shown in the example: they should never depend upon a right angle taken with the cross-staff for their relative positions.

These maps are now protracted by the measurers with sufficient accuracy to be pieced together, and form *talook* maps for revenue and topographical purposes.

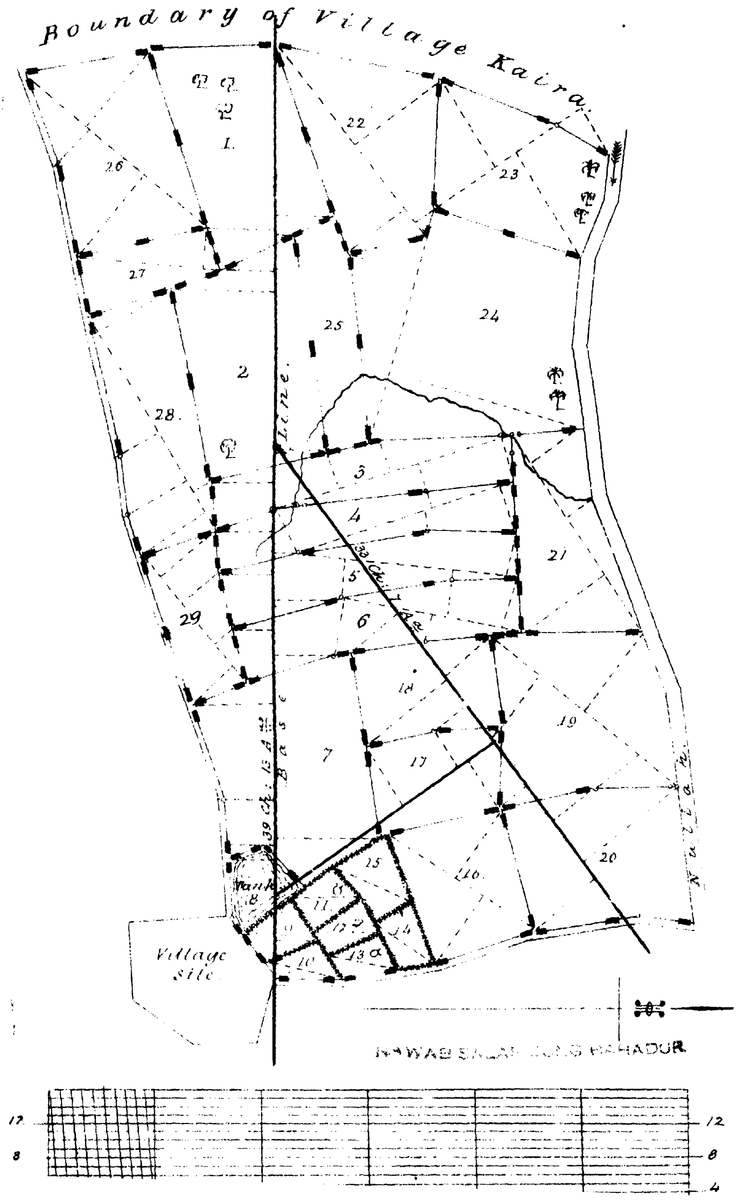
All the Measurer's observations in the field are finally entered and abstracted into his fair field-book. These books are lithographed and supplied to the measurers, by which means a great deal of their valuable time is saved. It is calculated that the cost to the state of each working day of a good measurer in the fair season, is from Rs. 4 to 5, and it is a judicious economy to give him every assistance possible, so as to enable his time to be entirely devoted to his measurements in the field, and book work at his lodgings.

All the work that has been done in the fair season, has to be revised in the rains; the corrected results are tabulated in convenient forms, and two fair copies made of the village maps for the Classing Department, which is the next operation of the survey. It becomes nearly impossible to pursue field operations after the first fall of rain in June, and all the establishment return to head-quarters by the 15th of that month. As a rule those villages that have been measured by the worst measurers should be checked by the best. One of the most important of these operations, and the most troublesome, is the multiplication of the lengths and breadths of the internal figures, triangles and trapezoids, into which each survey number has been broken up by the chaining operations of the measurer. This used formerly to be done by actual calculation, but the product is now obtained from multiplication tables made up as far as 40 chains by 40 chains, and lithographed for the purpose. These tables were for a long time a great desideratum on the surveys, and their introduction has effected as much good on the Bombay side as Boileau's Traverse Tables did in Bengal and the North Western Provinces, for the traverse system of survey in force there. One-quarter of a leaf of these tables is shown here, embracing the multiplication of all intermediate quantities from 28 to 29 chains by 36 to 37 chains. If, for example, we want the multiplication of 28 chains 13 annas by 36 chains 11 annas, the result $\overset{\text{CH.}}{1057}$-$\overset{\text{AS.}}{0\text{-}15}$ is obtained at once from the tables without the trouble of working out a long sum in duodecimals.

When these tables were being lithographed, the proof sheets were carefully tested and collated with a copy of the tables made up by hand, and after being struck off, a trifling reward was offered to any one who would discover errors in the results. They may be considered now as arithmetically accurate. These tables, together with the assessment tables, which will be described afterwards, have so greatly facilitated the very onerous calculations that had formerly to be done by hand, that a considerably greater amount of work can now be got through by the men in the fair season, as they finish their work earlier in the monsoon, so as to enable them to pass a longer time in the district.

By the use of these tables each measurer is able to work much more accurately, and the value of the bad computers is raised to nearly a level with that of the good. As an additional precaution against error, the entire area of each number is tested by means of the talc square on the map, so that it is next to impossible that any serious error in area can remain undetected. All these processes gone through in the rains, are tested to the extent of 10 per cent. by the Assistant himself, and the registers and

BOMBAY REVENUE SURVEY.



documents embodying the results are sent at the close of the recess to Superintendent's office for distribution to the Classing branch, in which the relative value of the soil and water in each of these Survey Numbers has then to be determined.

All the records of the survey are kept in the vernacular language of the province in which the operations are progressing. The notation is the same as the European or the Arabic system; and the finished digits or numerals should preferably be used, and not the original traces or strokes, which represented numbers in the first instance, and from which the present digits have been formed.

MAHRATTA.	1	2	3	4	5	6	7	8	9
Strokes or traces,	–	=	≡	·|·	|–	|=	|≡	||	||–
Finished digits,	१	२	३	४	५	६	७	८	९

The construction of the first three numerals from the original strokes, is readily understood, but the process of transition in the remaining numbers, four to nine, is not so clear; but if the original strokes be written with rapidity, a character will be produced closely corresponding with the form of the finished digit.

Natives are very prone to employ these original strokes, and more especially to represent fractions and subordinate denominations by these signs, but they can be so easily altered, by adding fresh strokes, that a great facility is given by their use to the falsification of the records, and their employment should consequently be interdicted. To illustrate this point, of we take the number 5, as formed by one perpendicular and one horizontal stroke, it is evident that by adding one or more strokes of one or both these sorts, it can be altered without fear of detection into any other number whatever, except exact multiples of 4. The completed numeral should therefore be used throughout all the survey operations, as not being capable of easy alteration, and readily detected if tampered with.

The Classification should now be considered; and it is found that the chief circumstances affecting the value of land within the limits of the same village are—natural productive capability—distance from site of village, as affecting facilities for cultivation and manuring—and, in the case of garden or rice land, the supply of water for irrigation. If rules cannot be laid down for all these points with arithmetical accuracy, still as near an approach as possible should be made thereto, as our results will then be more uniform; the application of a rigid European test, similar to that in the measuring branch, can be enforced, and as little as possible will be left to the individual judgment of the classer, and this last point is one of great importance where a trustworthy agency cannot be procured.

In determining the elements which make up the first of the above, the productive capability of the soil, there were found to be three distinct orders of soil, of different degrees of fertility, which may be called from their color, black, brown and yellow, or gravelly, respectively. The relative value of these soils among themselves may be considered as in a great degree proportional to their depth, as on that depends their value for agricultural purposes, by enabling them to imbibe and retain moisture, which is the great element of fertility in India. By means of these considerations, we obtain an outline of a scale by which to gauge these soils among themselves; and in order to be able to draw up rules embodying these principles, we find that a depth of 1¾ cubits, say 2 feet 7 inches English measure, is ample to enable soil to retain the necessary amount of moisture, and that any greater depth is not attended with any increase of water-carrying capability. Yellow earth is but rarely found of a greater depth than one cubit, and from its more porous nature, in comparison with black and brown soils, that depth is found to retain water as well as any greater depth. Assuming therefore our maximun standard as 16 annas or 1 rupee for pure black soil of depth, the soils of inferior value to this will range themselves in order as in the following table:—

Class.	Relative value of class in annas or 16ths of a rupee.	SOILS.		
		1st order.	2nd order.	3rd order.
		Of a fine uniform texture, varying in color from deep black to dark brown.	Of uniform but coarser texture than the preceding, and lighter also in color, which is generally red.	Of coarse gravelly or loose friable texture, and color varying from light brown to gray.
		Depth in cubits.	Depth in cubits.	Depth in cubits.
1	16	1¾	...	...
2	14	1½	1¾	...
3	12	1¼	1½	...
4	10	1	1¼	...
5	8	1¾	1	...
6	6	½	¾	1
7	4½	¼	½	¾
8	3	...	¼	½
9	2	...	...	¼

		33			34			35			36			37			38			39		
2	10	27	13	2	27	13	7	27	14	0	27	14	5	27	14	10	27	15	2	27	15	7
0	8	28	11	1	28	11	6	28	11	11	28	12	4	28	12	9	28	13	2	28	13	7
8	7	29	9	0	29	9	5	29	9	10	29	10	4	29	10	9	29	11	2	29	11	7
6	5	30	6	11	30	7	4	30	7	9	30	8	2	30	8	8	30	9	1	30	9	7
4	5	31	4	10	31	5	4	31	5	9	31	6	2	31	6	8	31	7	1	31	7	7
2	3	32	2	9	32	3	2	32	3	8	32	4	1	32	4	7	32	5	0	32	5	6
0	2	33	0	8	33	1	2	33	1	7	33	2	1	33	2	7	33	3	1	33	3	6
4	1	33	14	7	33	15	0	33	15	6	34	0	0	34	0	6	34	1	0	34	1	6
2	0	34	12	6	34	13	0	34	13	6	34	14	0	34	14	6	34	15	0	34	15	6
9	11	35	10	5	35	10	11	35	11	5	35	11	11	35	12	5	35	12	11	35	13	6
7	9	36	8	4	36	8	10	36	9	4	36	9	11	36	10	5	36	10	11	36	11	6
5	8	37	6	2	37	6	9	37	7	3	37	7	9	37	8	4	37	8	10	37	9	5
3	7	38	4	2	38	4	8	38	5	3	38	5	10	38	6	4	38	6	11	38	7	5
5	5	39	2	0	39	2	7	39	3	2	39	3	8	39	4	3	39	4	10	39	5	5
5	5	40	0	0	40	0	7	40	1	1	40	1	8	40	2	3	40	2	10	40	3	5
3	4	40	13	11	40	14	6	40	15	1	40	15	8	41	0	3	41	0	10	41	1	5
1	2	41	11	10	41	12	5	41	13	0	41	13	7	41	14	2	41	14	10	41	15	5
9	1	42	9	8	42	10	4	42	10	10	42	11	6	42	12	2	42	12	9	42	13	4
7	0	43	7	7	43	8	3	43	8	10	43	9	6	43	10	2	43	10	9	43	11	4
4	11	44	5	6	44	6	2	44	6	9	44	7	5	44	8	1	44	8	9	44	9	4
2	10	45	3	5	45	4	1	45	4	9	45	5	5	45	6	1	45	6	8	45	7	4
0	8	46	1	4	46	2	0	46	2	8	46	3	4	46	4	1	46	4	8	46	5	4
14	7	46	15	3	46	15	11	47	0	7	47	1	4	47	2	0	47	2	8	47	3	4
12	5	47	13	2	47	13	11	47	14	7	47	14	3	47	15	0	47	15	8	48	0	4
10	5	48	11	1	48	11	10	48	12	6	48	13	2	48	13	11	48	14	7	48	15	4
8	4	49	9	0	49	9	9	49	10	5	49	11	2	49	11	11	49	12	7	49	13	3
6	2	50	6	11	50	7	8	50	8	4	50	9	1	50	9	10	50	10	7	50	11	3
4	1	51	4	10	51	5	7	51	6	4	51	7	1	51	7	10	51	8	7	51	9	3
2	0	52	2	9	52	3	6	52	4	3	52	5	0	52	5	9	52	6	6	52	7	3
15	11	53	0	8	53	1	5	53	2	2	53	3	0	53	3	9	53	4	6	53	5	3
13	10	53	14	7	53	15	4	54	0	1	54	0	11	54	1	8	54	2	5	54	3	3
11	8	54	12	6	54	13	3	54	14	0	54	14	11	54	15	8	55	0	5	55	1	3

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Class.

	11			12			13			14			15		
0	1032	12	0	1035	0	0	1037	4	0	1039	8	0	1041	12	0
0	1034	8	11	1036	12	12	1039	0	13	1041	4	14	1043	8	15
4	1036	5	6	1038	9	8	1040	13	10	1043	1	12	1045	5	14
4	1038	2	1	1040	6	4	1042	10	7	1044	14	10	1047	2	13
8	1039	14	12	1042	3	0	1044	7	4	1046	11	8	1048	15	12
2	1041	11	7	1043	15	12	1046	4	1	1048	8	6	1050	12	11
2	1043	8	2	1045	12	8	1048	0	14	1050	5	4	1052	9	10
6	1045	4	13	1047	9	4	1049	13	11	1052	2	2	1054	6	9
[illegible]	1047	1	8	1049	6	0	1051	10	8	1053	15	0	1056	3	8
[illegible]	1048	14	3	1051	2	12	1053	7	5	1055	11	14	1058	0	7
1	1050	10	14	1052	15	8	1055	4	2	1057	8	12	1059	13	6
1	1052	7	9	1054	12	4	1057	0	15	1059	5	10	1061	10	5
[illegible]	1054	4	4	1056	9	0	1058	13	12	1061	2	8	1063	7	4
2	1056	0	15	1058	5	12	1060	10	9	1062	15	6	1065	4	3
2	1057	13	10	1060	2	8	1062	7	6	1064	12	4	1067	1	2
[illegible]	1059	10	5	1061	15	4	1064	4	3	1066	9	2	1068	14	1

By the above table we are enabled then to determine the relative values of these soils amongst themselves; but in addition to the color and depth of the soil, there are also other elements affecting its productive capability; in almost all soils there is present a *mixture of deteriorating ingredients*, or circumstances which tend to diminish its crop bearing powers. Those of the most ordinary occurrence are distinguished by the following conventional marks in the classers' field-books, as being convenient for notation—

∴ Denotes a mixture of minute fragments or nodules of limestone, "choon kud."

V Denotes a mixture of sand, called "walsur."
| „ sloping surface, "ooturwut."
× „ want of cohesion amongst the constituent particles of the soil, "reswut."

∧ Denotes a peculiar mixture more or less impervious to water, "kunul."
~~~ „ liability to be swept over by running water, "doopun."
□ „ an excess of moisture from surface springs, "oopulwut."
> „ a mixture of large nodules of limestone, "gochur."

The elements which are to be taken into consideration, therefore, in determining the value of dry crop land, are color, depth, and the presence or otherwise, of deteriorating ingredients or circumstances, which are technically called "faults" in the department. One such fault lowers a soil in which it is found one class in the above table, two lower it two classes, and so on, as shown in the following example. In effecting the classification of a field, the classer with the aid of the village map, enters an outline of its shape in his field-book, which he divides by intersecting lines into a number of equal compartments, sufficiently numerous to give a fair average valuation of the soil by an examination of the depth and quality in each compartment. These particulars and the class in which the soil falls, are noted within each compartment.

NORTH.

7 $\frac{3}{4}$ ...	4 ∧ ∧ ~~~ $1\frac{3}{4}$.	3 ~~~ $1\frac{3}{4}$.	1 $1\frac{3}{4}$.	2 ∴ V $1\frac{1}{3}$.
6 1 ...	5 1 ..	4 ∧ $1\frac{1}{2}$ ..	3 $1\frac{1}{2}$ ..	3 V | $1\frac{3}{4}$.
~~~

The figure in the left hand lower corner of each square indicates the depth of the soil, and the number of dots under it, the order of soil to which it belongs; one dot signifying the 1st; two the 2nd; and three the 3rd, order. The conventional marks in the right hand upper corner show the faults, each of which degrades the soil one class; from the order of soil, the depth, and the faults, is determined the class of relative value to which the compartment belongs, as indicated by the figure in the left hand upper corner. To take the instance of the lower compartment on the right of the field, the depth is entered at 1¾ cubits, and the soil is of the first order, as shown by the single dot immediately below. This order and depth indicate the first class of relative value, but the presence of two faults (a mixture of sand and a sloping surface) indicated by the signs V I, requires the soil to be entered in the third class, as denoted by the figure 3, in the upper left hand corner of the compartment. It will also be seen from the example, that the same fault is sometimes entered twice in one particular compartment, which means that it exists in so great a degree as to require the value to be lowered two classes in consequence. In the right hand upper compartment also, it will be observed that two faults (limestone and sand) are bracketted together, by which is indicated that there is about half a fault of each and that the two together make up one full fault and lower the soil one class. The size of the compartments into which the number is divided varies with the area, and the uniformity or otherwise of the soil. In large numbers with a uniform soil, each compartment may be about two acres, but with smaller numbers, one acre or even less, if the soil vary, would be a proper size. The field operation is performed by digging a hole in the centre of each compartment, and gauging the depth of soil with an iron bar marked with cubits: the color of the soil and the faults are ascertained from an inspection of a clod of earth, taken up in the hand.

The Classer next proceeds to strike an average for the entire number from the value of these compartments, which is done in the following manner:—An abstract is entered in the book showing the number of compartments of each class, together with their aggregate value in annas, taken from the table; and the sum of these annas divided by the number of compartments, gives the average value of the number. The average value for the above example would be entered as follows:—

Class.	Number of compartments.	Value of shares in annas.
1	1	16
2	1	14
3	3	36
4	2	20
5	1	8
6	1	6
7	1	4½
Total, ...	10	104½
		Rs. 0-10-5 average value.

The classer also enters in his book all extrinsic circumstances affecting the value of the field, such as distance from drinking water, both for men and cattle, number and kind of fruit trees, &c. These books are also furnished ready lithographed to the classer similarly as to the measurers; and by saving him a considerable amount of hand copying, enable him to pass a greater portion of his time in the field. The comparison and testing of the numbers is also greatly facilitated by having each number with all its details on a separate page.

The actual determination of the quantity of deteriorating ingredients necessary to constitute a fault, by which the value of the land is reduced two annas in one rupee, or 12½ per cent., can only be correctly arrived at by constant practice whereby the judgment is fully confirmed. As the percentage of reduction is assumed as the invariable element, being always 12½ per cent., it requires a nice judgment to determine the exact amount of each ingredient or fault necessary to diminish the fertility of the land to that precise extent. It is a most difficult matter to establish a uniform standard of judgment on these points among the classers; but it is of such importance that it should be always kept in view. As an aid to its attainment, at the commencement of the working season, the Assistant assembles all the classers of his establishment at some village where a great variety of soils and cultivation obtains, and accompanies them regularly every day in the field for about ten days, until they are able to classify with precision and consistency. Where so much depends on the individual classer, in spite of all the rules we can lay down, it is evident that the older a classer is, the less liable he will be to err in his judgment; as a rule, we should guard against the employment of men too young for this branch. Amongst the most effective classers in an establishment, will be found those who have worked for some years as measurers; they learn the work quickly, their previous training and knowledge enable them to class independently after a comparatively short time of instruction, and they can bring forward the faults of the measurer whose work they may be classing, and thereby provide an additional check on the accuracy of that branch of the operations.

The soils classed by the European Assistant are considered as a test of the classers' work, similarly to the system which obtains in the measuring department. He is, however, at a disadvantage in comparison with an Assistant in charge of a measuring establishment, inasmuch as he has no means of lightening or shortening the test labor, in any way commensurate with that effected by means of the theodolite for the former officer. It is evident from this that he must have fewer classers under him, or else that a less percentage of test must be taken; and as this latter would be objectionable, from 5 to 10 per cent. of test being considered indispensable to induce reliance on the whole work, the other expedient is adopted of decreasing the number of men; and from twelve to fifteen classers is placed under him as being the most that an Assistant can properly supervise.

When land is found to be in possession of the means of Irrigation, the propriety or otherwise of imposing an extra assessment on account of the increased productiveness of the land, ought to be determined by a consideration, whether the irrigational work which furnishes the supply has been built and kept in repair by Government, or is the product of private enterprise. Almost all tanks and *anicuts*, or *bundharas*, have been constructed by the State, and kept in repair by the present Government, and the imposition of an extra assessment cannot in any way prevent the construction of new ones, as these works are in fact beyond the means of individuals to execute. Wells, on the contrary, when intended for irrigational purposes, are almost always the result of private enterprise; but they are not exempted for that reason, inasmuch as some extra assessment has always been levied on them, and it has not been considered advisable to sacrifice a source of revenue of considerable amount in the aggregate, on account of the somewhat theoretical objection which exists to an enhancement of taxation on land thus irrigated, as having a tendency to discourage the digging of new wells.

The classification of water privileges where irrigated crops are grown, is a difficult and complicated subject, and presented for a long time considerable obstacles to the formation of detailed rules for the purpose; this has been at last effected, but there are still some points on which the opinions of the most experienced officers differ. The operations require experience and judgment, and the superior classers are employed on these duties, as involving more responsibility than merely dry crop classification.

Where land is irrigated from tanks or dams, the duty of distributing the water is usually entrusted to a person called the "*Putkurree*," who enjoys some *enam* land for this purpose. The interests involved are not generally of any very extensive nature, the quantity of land irrigated from one of these works but rarely exceeding 50 or 100 acres, and the distributing channels are not provided with meters or gauges. A great facility under these circumstances, is given to the cultivators to obtain water surreptitiously, either by collusion with the putkurree, or by cutting the canal, which can be readily done at night. Those more wealthy and influential, in these and other ways, generally obtain more water than their due, to the detriment of their less fortunate neighbours, and are thereby enabled to raise superior garden produce which requires much water. Those revenue officers who are rather inclined to accept this state of affairs as unavoidable, as having its origin in human nature, and being incapable of amendment, propose to assess the crops grown rather than the land; and, by placing a rate upon the crops proportional to the amount of water that each consumes (those that require abundant waterings, as for instance sugar-cane, being placed highest, and thence downwards in gradations); they argue that the amount of water each individual has taken can be ascertained from the measurement of its resulting crop, and the assessment he ought to pay is at once found by multiplying the area by the modulus, or rate fixed for the particular crop grown; and there can be no doubt but that if the rate for each distinct crop be properly fixed by those well acquainted with garden cultivation, the result attained by this system will give a close approximation to the true assessment that each ought to pay. The objections to the system are, that it requires an annual inspection and measurement of crops, and that the amount each cultivator pays, fluctuates from year to year, and the system is hardly applicable to irrigation on an extended scale. This method of assessment is called the *tinnuswar*, and although very ingenious, is more perhaps suited to native ideas than to ours. Those who oppose this system would wish to see the water-rate paid by each cultivator, fixed at an invariable amount on the area irrigated, which would be proportional to the water he ought to get, or was supposed to get, from the canal. Nothing could be fairer than this, and more consonant with European ideas, if it could only be carried out; but in practice, it is found that if the water-rates be permanently fixed, the system then possesses no power to meet and control those irregularities in the distribution of water, for which the tinnuswar or crop system, provides so excellent a check; and in consequence, the cultivation of sugar-cane and other water-consuming crops, is fostered on the lands of certain influential cultivators, and the result is that those whose water has been unduly appropriated, throw up their claim thereto and obtain a remission of assessment, so that the area under water-produce gradually contracts, the revenue declines, and a few cultivators make handsome profits.

The chief elements that form the value of a water supply from an artificial canal are quantity, quality, and the position of the ground, whether low-lying or elevated, as enabling the soil to retain moisture longer. The soil itself is classed very much according to the system laid down for dry crops; with this difference, that the water being supplied artificially, the depth of the soil does not increase its value to the same extent as in the case of dry cultivation, nor do the presence of faults or deteriorating ingredients decrease its value in the same proportion.

The quality of the water supply is soon ascertained by local enquiries, and from the nature of the crops grown. The quantity is determined by the abundance of the supply and the number of months for which it lasts. The following six classes are sufficient in practice to embrace all qualities of water supply from a canal, from the very best of that sort down to that obtained from the rain-fall alone.

Class 1. Where the supply is obtained from a good tank or river, in which the water lasts till the end of March or April, and the land lies sufficiently low to permit of the better kinds of sugar-cane being grown every second or third year.

Class 2. Similar to the above, but the land being somewhat more elevated, only the inferior kinds of sugar-cane can be grown.

Class 3. When sugar-cane can only be grown should the rains prove very favorable; and this may be the case when the supply of water is the same as class 2, but with the land still more elevated; or, secondly, when the soil is not elevated, but the supply of water fails after the end of December or January; or, lastly, when there is no artificial irrigation, but the land is in a very low situation.

Class 4. When the soil is irrigated from an artificial canal, but is in too elevated a position to produce sugar-cane, but possesses sufficient moisture to admit of a rice and an after green crop; or if the after green crop cannot be grown, the moisture should be sufficient to produce an excellent rice crop; or when the land is not irrigated but is sufficiently low-lying to produce the above crops.

Class 5. The same as the above, only no after crop can be raised.

Class 6. When the land is not supplied artificially, but only by rain, and is in an elevated situation.

The supply of water to both rice and garden land is classed according to the above rules, but the 6th class is evidently not applicable to garden cultivation.

In classing the water obtained from Wells, the value depends upon the quality, whether sweet or brackish, the quantity or the number and size of the springs, and the expense of drawing it, which increases with the depth; also, whether there is sufficient land under the well to allow of a rotation of dry and wet cropping. All these points are noted by the classer, as well as all collateral points necessary to enable a judgment to be arrived at concerning the area the well is capable of irrigating, such as the number of water bags used, length and breadth of the surface of the water, depth of water in the well, and number of hours it can be drawn, especially in the hot weather.

It is as well here to notice the manner in which the assessment is levied eventually on this kind of land, before quitting the subject. It has always been considered good policy to encourage irrigated cultivation by imposing a low assessment, so that the profits upon the capital employed may be greater than is realized on that engaged in dry crop cultivation; so that the cultivators may acquire substance, and other agriculturists may be thereby stimulated to engage in this superior kind of culture. This was not the policy of native rulers, and our enquiries into the former condition of this class of men elicited the fact that, owing to an excessive assessment, they were little if at all better off in their circumstances than other agriculturists. In some extreme cases the assessment was found to be Rs. 40 per acre, and the proprietors were in consequence nearly ruined. The rates of the existing assessment, and the condition of the cultivators, as well as other considerations, enable the settlement officer to judge of the extent of reduction necessary, and he accordingly fixes the maximum rate to be levied on canal or well irrigation; the rates for the lower classes can then be easily adjusted.

The Area and Class of the Soil and Water of each survey number have now been determined, and there remains to be shown how the Assessment is to be imposed on each. It has been found by experience, that on an average about one talook, or at the most two, can be conveniently settled by a Superintendent of survey, in each year, without prejudice to his other duties of check and control.

The strength of a survey is fixed at six measuring and two classing establishments, which are sufficient to finish this amount of work annually for the Superintendent's settlement. The revised assessment is introduced into entire talookas each year; as the records and revenue management of these, being perfectly distinct from the other districts, afford readier data to work with than would be the case if portions or fractions of these districts were dealt with separately. The first question then for consideration is the extent of territory within these districts, for which a uniform standard of assessment is applicable. Many portions of a district are naturally far more favorably situated than others, and these advantages consist for the most part of a superiority of climate, proximity to markets and outlets for produce. These are considerations of a permanent nature, and on which an enhanced assessment may be properly levied by Government; all other differences between districts caused by greater agricultural skill and increased capital of the cultivators should not be taken into account in determining the absolute assessment, being not of a permanent character, and as such a system would act as a tax on intelligence and progress, and have a tendency to produce a slovenly and unremunerative style of husbandry.

The district to be assessed is therefore divided up into such distinct portions or groups of villages, as on enquiry are found to be well defined from each other by strong natural differences of climates; and a different rate of assessment is imposed upon each proportioned to its ability to liquidate it. These natural differences are hardly ever found to be so numerous and varied in a talook of moderate size, say of 100 villages or so, as to demand division into more than three or four of these groups or classes, and these distinctions are rarely so strongly marked as to need the difference of absolute assessment between each of these groups to be more than 20 or 25 per cent.

It only remains now to fix the absolute amount of assessment which it may be considered advisable to levy from the entire district about to be settled, as when once this is determined, the ratio in which the relative values of the numbers, as obtained from a multiplication of the classification by the acreage, is to be enhanced, will be the quotient obtained by dividing the former by the sum of these latter. This will give a mean ratio, and if the enhancement of some villages above this ratio, be counterbalanced by others being at a less ratio, the result will be the aggregate assessment required. The more usual method, however, is to effect the object by a kind of trial and error; by a consideration of the assessment of surrounding districts, and other matters, rates are fixed on the groups of villages, and the result of the assessment produced by multiplying by these rates and adding the totals together, is compared with the amount that is desired to be imposed, and then slightly re-adjusting these rates again, until the required result is obtained.

It is a very complicated question to determine what can safely be taken by the State, and still leave a sufficient surplus with the ryot to render him capable of improving his circumstances and extending his cultivation; and it is one which probably admits of no exact solution. Any one who attempts to ascertain with minuteness from the cultivators, the amount of their expenses for the cultivation of any given area and the value of the crops grown thereon, so as to be enabled to judge of the amount of assessment that can safely be levied, will find them unable to supply him with any trustworthy data. Instead, therefore, of attempting the solution by direct means, a method quite as efficacious for the attainment of the purpose in view can be obtained in an indirect manner, by enquiring into the past revenue management of the district and the relative amount and effect of the collections of each year. The cultivator has no other way of employing his spare capital than by an improvement or increase of his holding, and in those years in which the collections have been moderate, the cultivation may be reasonably expected to have increased during the succeeding year. This effect would also be produced by favorable seasons, by a sudden extension of the export trade and other causes; and, on the other hand, a decrease in cultivation may have been caused by a drought or famine or by a contraction of the export trade. In fixing upon those years when cultivation was extending itself, in order to ascertain the origin or causes of this prosperity, it must clearly be ascertained that the increase of cultivation has been due to the lowness of the preceding collections, and not to other extraneous causes, and we may then rest assured that the agriculture of the country would continue to advance in prosperity if the State demand were lowered to this amount. The cultivator would then be in a condition to meet the full Government assessment, and to make yearly improvements or additions with the surplus left him. Under the old system, the assessment on the land has been so heavy, that it could only be discharged in years of exceptional prosperity, and any little surplus left with the cultivators in any one year was eventually screwed out of them in succeeding years, and cultivation again declined.

The information collected on the subject of past revenue settlements should enable us to trace with facility the mutual influence on each other of the assessment collections, and area in cultivation, and it will be found to be very difficult to obtain a clear conception of the subject from figured statements, however elaborate these may be. It can be done best by means of diagrams constructed so as to exhibit in contiguous columns by linear proportions, the amount and fluctuations of the assessment, collections, and cultivations for each of the years to which they relate. The specimen

Periods.	Assessment on cultivated land according to diagram.	Other items comprising grazing tax on farms, sheep, and fruit trees, &c.	Revenue of villages, not included in diagram.	Total revenue from Government land.	Estimated survey rental.	Excess of survey rental over realizations of past years.
Average of last 28 years,	77,406	1,956	10,707	90,069	1,15,000	24,931
Average of 5 years ending 1833-34, ...	63,280	1,508	10,707	75,495	1,15,000	39,505
Average of last 12 years,...	76,188	2,158	10,707	89,053	1,15,000	25,947
Last year, 1845-46, ...	71,820	4,988	10,131	86,939	1,15,000	28,061

herewith given, with the necessary explanation and the figured abstract, was drawn up by Major Wingate, when submitting his proposals for the revision of the assessment in the Bunkapoor Talooka, in the Dharwar collectorate in the year 1846, and will serve to explain the method of drawing up these synopses of the past revenue history of a district. Similar diagrams accompany all settlement reports submitted by the Superintendents of Surveys for the introduction of the revised assessment into new districts; they refer only to villages under direct Government control, and the items of information are alike for each year, and bear reference to the same villages.

The main object of the survey is to afford relief to the cultivators of Government land, but the operations are extended over all alienated land included within the limits of villages under direct control. No reductions are made in the cesses levied on alienated land, but when it is found that these are in excess of the Government demand, the surplus is remitted to the alienee, and the land entered in the records as Government. There are numerous items of land revenue and "*hucks*," or dues to village officers and others, which are consequently excluded from the diagram, and these have to be separately noted and taken into account in order to complete the entire revenue record for the year in which the revised rates are introduced.

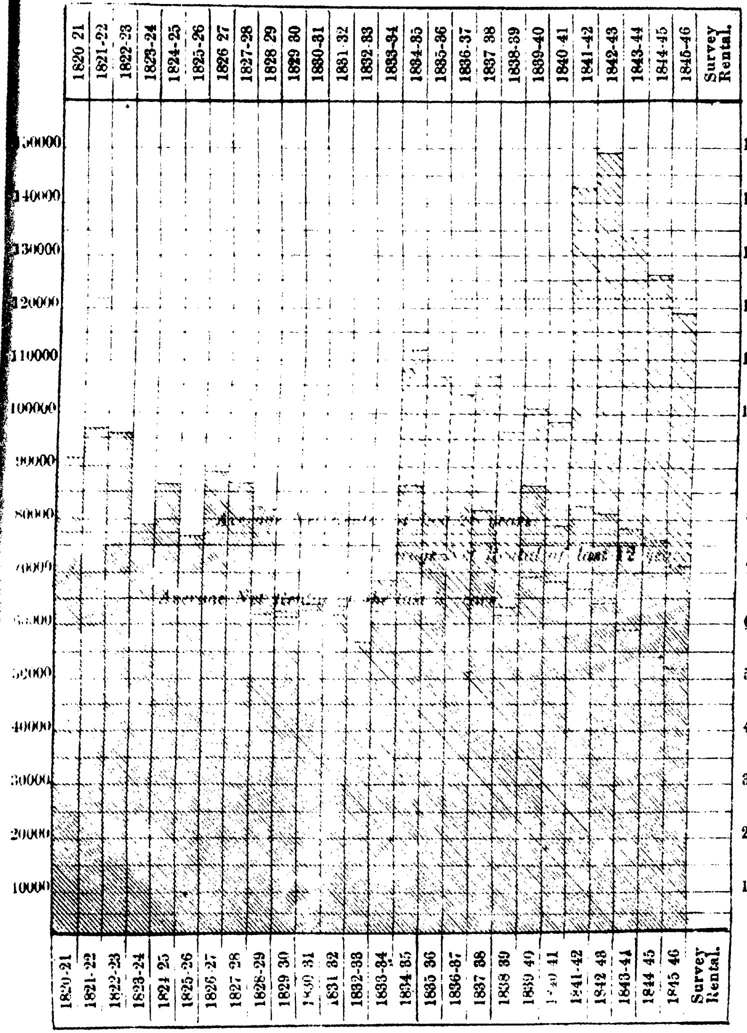
In the diagram above alluded to, Major Wingate selected the years 1829-30 to 1833-34, both inclusive, as showing the amounts of collection under which cultivation had been steadily progressing, and as furnishing us in consequence with the data necessary to settle on. It will be as well to show at this place how the final result is arrived at from the original observations in the field of the measurers and classers, by means of an example, so as to complete our view of the subject. Let the area of the "Number" be 27 acres 33 goontas, the classification 15 annas and 1 pie at a distance from the village site requiring a reduction of 2 annas, and that it be one of a group of which the maximum rate is Rs. 2-4 for dry crop. The classification reduced by 2 annas for distance from villages becomes 13 annas and this multiplied by Rs. 2-4, gives Rs. 1-13-5, which is considered as Rs. 1-13-6, it not being necessary to have any rates of less than half an anna. The product of this rate by 27 acres 33 goontas, is obtained from the assessment tables, of which a quarter of a sheet is here shown, and the result Rs. 51-4-10 is the assessment required.

It has been already stated that all imposts of a pernicious nature were abolished and others absorbed into the new assessment. And an example of each of these processes will serve to show what has been accomplished in each case, and the amount of benefit that has been conferred. A striking example of an impost at once hurtful to the cultivators, and through them to the State, is furnished by the tax that used to be levied on fruit trees.

The usual practice was to sell the produce of all such trees that stood on Government land to the highest bidder, whoever he might be, and in the event of the occupant himself not outbidding everybody else, the purchaser of the usufruct of such trees would have a right of way across his land, and of placing watchmen there to guard the fruit; this would be to the manifest detriment of both parties, the cultivator and the purchaser. The worst effect, however, of this impost was that no one was ready to plant trees, as the proprietorship was not guaranteed to them. Many talookas admirably adapted from the nature of their soil, for bearing mango, jack, tamarind, and other fruit trees, were found to be almost devoid of these valuable products, owing chiefly to the operation of this tax; and, after its abolition, the usufruct being guaranteed under the new rules to the occupant of the land, a great extension to planting was given, and numerous fine groves, chiefly in the neighbourhood of towns, have sprung up since then, while the planting of timber trees on the boundaries of numbers has been engaged in with spirit by the occupants. The attention of Government having been once turned to this subject, it was resolved with praiseworthy liberality, to encourage the production of these ornamental and useful adjuncts to the lands of villages, by permitting the assignment of a percentage of the land, in *enam* or rent free, to whomsoever would undertake to plant groves of valuable trees thereon, and the self-interest and pride of the villagers are alike engaged in forwarding these plantations. The produce of fruit trees standing in Government waste is still sold annually to the highest bidder, but the proprietory right in them, in addition to the occupancy of the number in which they stand, is purchaseable outright, once for all, at any one of these auction sales.

An illustration of taxes not perhaps of a pernicious nature in themselves, which have been absorbed in the land-tax, is afforded by the sheep and grazing tax. The former of these was levied on every hundred sheep, and has now been absorbed in the higher price which is obtained for the grazing of the waste lands, which, under the new rules, are sold annually to the highest bidder. The grazing farms are being gradually absorbed with the extension of cultivation, but so long as any waste remains in a district, it is let out annually, number by number, in the manner above indicated. In addition to these there were numerous "hucks," or dues levied in kind by different officials; these have been all abolished and compensation awarded by Government, whenever they are equitably entitled to it, to the recipients.

...GRAM ILLUSTRATIVE OF THE EXTENT OF GOVERNMENT LAND IN CULTIVATION ANNUALLY ... 8 VILLAGES OF THE BUNKAPOOR TALOOK, WITH THE GROSS AND NET ASSESSMENT THEREON ...URING THE LAST 28 YEARS, IN SO FAR AS THESE ITEMS ARE ASCERTAINABLE FROM THE REVE...UE ACCOUNTS.



EXPLANATION.

The various items are measured by the Scale of Acres and Rupees carried across ... Diagram.

The height of the Dotted Line carried across each column marks the extent of the ...ltivation in Acres, and that of the upper Dotted Line the area of the whole Go...rnment Land.

The heights of the Darker Columns indicate the Net Rental, and of the Lighter ... Gross Assessment, on the Land in Cultivation.

... Lines mark the average Net Rental of the years indicated by ... of the

EXAMPLE.

In 1845-46.

Extent of Cultivation in Acres, ...

Gross Assessment on the same, Rupees, ...

Net ditto ditto..............

... of Arable Waste in Acre

In all the districts that have been settled for many years, the revenue has been found to have recovered itself from the extensive reductions made at the time of the introduction of the Survey rates. Its success has been more marked in those districts where there was great scope for the extension of cultivation; and it may be said that wherever large quantities of land are out of cultivation, the fact may be accepted as an indication that the assessment is too high, and that the revised rates should rather err on the side of liberality than the reverse. In the extensive province of Khandeish, which is about half the size of Ireland, the population was about 60 to the square mile at the time of the Survey operations, although from the fertility of its soil, it could easily have subsisted four times that number, and the waste land was of such extent that in many talooks not even the attempt was made to divide it into Survey Numbers. The results of the survey operations in that province will, there is no doubt, in the course of a few years, afford a most striking illustration of the wisdom of those liberal concessions which have been lately granted. The provinces that appear to be exceptions to the rule of extensive reductions, are those whose history has not been so turbulent as the purely Mahratta provinces; the Concans, North and South, and the large opulent province of Goojerat, escaped in a great degree the scourge of war, with its accompanying evils; these districts have been nearly fully populated and cultivated since the period of the British Government, and any benefit that could occur either to the inhabitants or to the State, from a reduction of the assessment, is so trifling, as to demand but a moderate concession.

Another argument, if any more be wanted, in favor of liberality, might be found in the state of the ryots, who were almost always in a state of indebtedness to the *sircars*, or money lenders. In many districts nine-tenths of the cultivators were thus in the hands of these capitalists, and their condition mainly depended upon the individual character of their creditors. In some parts the agriculture was kept up in a flourishing condition by the capital thus employed, the owners being sufficiently enlightened to keep their clients in tolerably easy circumstances; but in others, their condition of indebtedness was not mitigated by any such advanced views.

To sum up these remarks, the introduction of the revised assessment is in general attended by an extensive reduction in the land-tax to afford relief to overburdened districts; but in exceptional cases, this rule must be departed from, should there be no valid reason for adhering to it.

Under all circumstances, it can be said with truth of the survey, tha wherever the revised assessment is introduced into a district, the ryots ii the course of a few years have emancipated themselves from debt and ı new era of prosperity and progress has been commenced, which will secur the enduring loyalty of the inhabitants to the British rule.

Under the ryotwar system, the mass of the population is fostered an protected, but it must not be forgotten that the limit to the physical well being of a country cultivated by peasant proprietors, is soon reached Every one produces what is necessary for his own subsistence, and whe all produce the like commodities, there can be but little of that interna exchange and trade, which forms the chief national wealth; and the prosperity of the country must depend on a much narrower basis, the stat of foreign markets. This during the last few years has been unprecedently favorable, and the cultivation of cotton under the influence of th high prices ruling, has kept pace with the demand: it is not probable however, that these prices will be permanent, and as a fall takes place so will the area under exportable produce decrease and cause a reaction and a period of suffering to the population, unless the cost of production be in some manner correspondingly reduced. Government has all the advantages of the position of landlord to the cultivating classes, and can reserve for itself an ample return for its outlay on those extensive internal improvements necessary to increase the fertility of the soil, and maintain a constantly progressive state in their provinces.

In the above remarks on the Bombay Revenue Surveys, the printed records of Government have been liberally drawn upon, and in many places the phraseology has been preserved verbatim; these will be easily recognized by those conversant with the surveys, and it has not been considered necessary to mark them as extracts.

A. C.

APPENDIX.

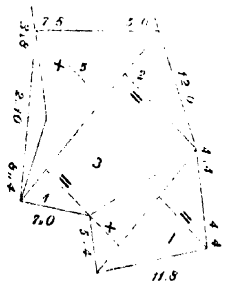
FORM OF MEASURERS' BOOK.

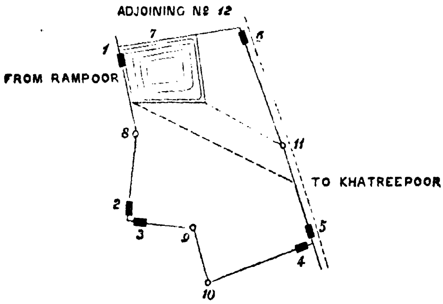
DATE, *1st.* Month, *November.* Year, 1863. Day, *Monday.* Present with the Survey in the Field, *Vittoo Keroo.* Patell, *Hurmunt Govind.* Coolcurnee, *Roonjee Suddaseu Multadar.*

Current Number.	Revenue survey Number.	Former Number, wholly or partly.	Name of field.	Soil. Kind.	Soil. Color.	Tenure.	Owner, *Nagojee Chimnajee.*	Present or absent.	Beegas.
17		21 wholly. 27 partly.	Sweet mango field.	Dry crop, rice and tank.	Red.	Tulput pusait service.	Occupant, himself.	0	10-12-0
							Cultivator, *Ramajee Govinda Cuddum.*	1	

The Boundary Marks to this number as shown below, will be constructed by Peon *Nursoo Deujee.*

NORTH.





Boundary Marks, numbered as follows, will be erected for this Number. Masonry pillars *none;* stones, 8, 9, 10, and 11; earthen mounds, 1, 2, 3, 4, 5 and 6; the marks on the side numbered 7, have been already constructed for Numbers formerly measured.

(Signed) WAMUN SUCCARAM, *Measurer,*
A. Estabt.

I inspected the above marks in the field this day, 10th November, 1863, and found them all completed, as above shown.

(Signed) WAMUN SUCCARAM, *Measurer,*
A. Estabt.

PAGE 17.

Direction whence the length is measured.		Length of Figure and distance where the cross-staff was applied.		Breadth in Chains.		Product.		
No.	Direction.	Offset.	Length in Chains.	Total.	Half.	Goontas	As.	$\frac{1}{16}$ A.
1	North-east,	= 5 12	..	6 12	..	..	..	..
		+ 5 0	15 4	4 0	5 6	81	15	8
		4 8		10 12				
2	North-east,	= 5 8	5 8	9 12	4 14	26	2	0
3		= 11 0	11 0	9 12				
				5 13	7 12½	85	9	8
				15 8				
4		= 4 2	4 2	5 13	2 14½	11	15	13
5		+ 8 4 13 0	21 4	9 8	4 12	100	15	0
	Goontas,	..	..	..	..	306	9	13
6	Deduct land included,	+ 8 2	16 2	1 2	0 9	9	1	0
	Remainder,	...	...	...	...	297	8	13
	Acres and goontas,	...	...	...	...	7 17	8	13
1	Rice land,	= 3 0 + 2 14 7 4	13 2	3 4 3 4 6 8	3 4	42	10	8
	Acres and goontas,					1 2	10	8
	Dry crop,	...	...	...	...	6 14	14	5
	Total, ..	...	...	...	...	7 17	8	13
1	Deduct for foot-path,	...	19 0	0 4 0 4 0 8	0 4	4	12	0
2	Tank.	+ 2 12 = 2 12 5 0	10 8	4 8 4 8 9 0	4 8	47	4	0
	Unculturable goontas, ...	...	...	...	...	52	0	0
	Culturable acres,	...	...	...	...	0 5	8	13

Kind of Soil.	Acres. Total.	Uncul-turable.	Remain-der.
Dry crop,	6 14 14	1 12 0	5 2 14
Rice, ...	1 2 10	...	1 2 10
Total, ...	7 17 8	1 12 0	6 5 8
Tale square,	7 20 0	...	...
Difference,	0 2 8	...	...

REMARKS BY ASSISTANT.

Fixed by the Classing branch.

Total acres,

Deduct unculturable,

Culturable,

FORM OF CLASSER'S BOOK.

DATE, 1*st*. Month, *March*, 1863. Present in the field with the Classer Patell, *Hurree Bhaie Tcchabhaie.* Coolcurnee, *Kaloobhaie Dhurmdass.*

NUMBER. Survey.	NUMBER. Current.	Former No.	Beegas.	Cultivated or waste when measured.	Name of field.	Soil.	Tenure.	Owner.
174	92	534 partly.	1-5-8.	Cultivated.	Munguldass.	Rice and dry crop.	Government.	Occupant, *Govinda bin Kalojee.* Cultivator, *none.* *Fallow.*
1-7 Area. 0-6 Unculturable. 1-1 Remainder.								

EAST OF PRECEDING NUMBER. (NORTH).

1 $1\frac{3}{4}$	2 ∧ $1\frac{3}{4}$	1 $2\frac{1}{2}$ 6 12 18	
2 $1\frac{3}{4}$	3 × $1\frac{3}{4}$	3 ∴∧ $1\frac{3}{4}$	5 ∧| $1\frac{3}{4}$
4 ∴∧| $1\frac{3}{4}$	5 ∧∨ ∴□ $1\frac{3}{4}$	6 |×∨ $1\frac{3}{4}$	7 | 1

CLASSIFICATION AS FOLLOWS:—

Dry Crop, ... 0-33
Cultivated, 0 Waste, ... 0-33

Class.	*Annas.*	*Portions.*	*Annas.*
1	16	1	16
2	14	2	28
3	12	2	24
4	10	1	10
5	8	2	16
6	6	1	6
7	$4\frac{1}{2}$	1	$4\frac{1}{2}$
8	3	0	0
9	2	0	0
Total, ...		10	$104\frac{1}{2}$
Unculturable, ...		1	
Total portions, ...		11	

Quotient, 10-$5\frac{4}{10}$

1 Distance from village, $\frac{1}{2}$ mile.
2 Cattle are watered from tank, $1\frac{1}{2}$ mile.
3 Wells in repair, 0. Out of repair, 1.
4 Deduct as unculturable, according to portions, 0-1.
5 This No. is (not) usually manured.

Rice, ... 0-8
Cultivated, ... 0 Waste, ... 0-8

Value of soil.	*Water.*	*Total.*	*Portions.*	*Annas.*
6	12	18	1	18

Measurer has omitted to enter the rice.

4-0
2-0 □ Length, 4-0; Breadth, 2-0; Area 8-0.

6 Measurer has (not) made any mistake.
7 Fruit trees, 3 mango, 2 tamarind, 1 jack.
8 Rice land is watered from tank in No. 105.
9 Bagayet crops grown at intervals of 2 years from a well.*
10 Rice is grown annually and other crops as well.
11
12
13
14
15
16
17

(Signed) RAMCHRISHN DAJEE, *Classer*, G. Establishment.

No. CX.

THE BOMBAY REVENUE SURVEY.

On the Principles and Practice of the Bombay Revenue Survey, by LIEUT.-COL. A. COWPER, R.E.

A PERIOD of nearly 30 years has elapsed since the Government of Bombay resolved upon instituting a Revenue Survey for the Presidency, and for this purpose two Engineer Officers, Lieuts. Wingate and Nash, were selected to conduct the professional part of the survey, which was considered at first as an experiment; and Mr. Goldsmid, a civilian, was associated with them to aid in the Revenue portion. Owing to the decease of Lieut. Nash, which occurred some years after his first appointment, the task of carrying out these surveys devolved upon Lieut. (now Major) Wingate and Mr. Goldsmid. By the joint labors of these two public officers, the experiment was brought to a successful issue, and the gradual extension of the operations over the entire presidency, and the facilities experienced by the department and its officers generally, may be considered as greatly due to the talents and influence of Mr. Goldsmid, who was afterwards Secretary to Government, and was always ready in that important post to aid the survey with his cordial and hearty support. To Major Wingate is justly due the careful elaboration of the original design of the survey, into the admirable administration which has proved so efficacious for the revival of agriculture in the Presidency, and the reports submitted by that officer for the introduction of the revised survey into the different districts, are amongst the most valuable of the Records of Government, and illustrate the ability with which the principles of the system have been carried into effect. The operations have now extended themselves over nearly the whole of the Bombay Presidency, embracing an area as large at least as Great Britain and Ireland. They form the basis of the Revenue administration for the realization of all taxes connected with the land, and these form by far the most important branch of the Bombay Revenue.

The districts composing the Presidency, consist for the most part of portions of the great Empire of the Mahrattas, who in their turn had conquered them from different native rulers. The previous history of these districts for several centuries had been one of anarchy and mis-rule, with but very few periods of good and prosperous Government. Under the most favorable circumstances, a native dynasty is too prone to consult its own immediate requirements and rarely looks beyond one generation, and the prosperity produced by any individual ruler who is an exception to this view, is not fated, in consequence, to be of any long continuance.

A graphic description of the condition of these provinces in the early part of this century, will be found detailed in the first two volumes of the Duke of Wellington's Despatches. The great Captain had campaigned over the entire country from the Tomgabuddra to the Nerbudda river, and was minutely acquainted with its state. On the 23rd July, 1803, he writes to the Governor General—"The whole of the Mahratta territory is unsettled and in ruins. Holkar's armies consumed the produce of last year, and owing to their plunder and extortion, entire districts were depopulated, and the habitations of the people destroyed. The consequence is that every man is a plunderer and a thief, and no man who can find anything to seize or to steal will cultivate the land for his subsistence:" and fourteen years of Mahratta rule elapsed after this before the introduction of the British Government.

The bases of the Revenue management in each Province, so far as can now be ascertained, were probably the Surveys instituted by the more capable and enlightened of the native rulers. These embraced an actual measurement and classification of the land, and an assessment fixed with reference to both; the processes were necessarily of a rough nature, but the standard of assessment being pitched very low, any inequality in the land-tax was not severely felt. The scheme of these original surveys varied in each province; in some the land measure was the standard or invariable element; in others the rate of assessment was constant, and the area of the land to which it was applied, varied with the class and productions of the soil. With each successive conquest the taxes originally levied on these settlements were increased, and fresh taxes imposed; but amongst these the Mahratta conquest stands out pre-eminent for the number and variety of the new cesses that their rapacious ingenuity enabled them to impose. The Mahrattas were our immediate predecessors, and on the establishment of the British Government, the revenue management of each district was found to be in a state of confusion; few, if any authentic records being forthcoming as a guide for our revenue officers to settle the country on. The land was as a rule greatly over-cessed in the aggregate, and the character of the component imposts were in many instances of a most pernicious nature. Under the whole however was the *ryotwar* system; the individual cultivator had under all rules been considered as the tenant of the soil, with Government as the landlord, and could not be ousted from his holding so long as he paid the land and other taxes, which were placed either upon his entire holding or upon the fields or produce contained in it.

The question therefore of introducing a uniform system of revenue management throughout the provinces, where this tenure, the ryotwar, prevailed, soon became one of paramount necessity in order to equalize and reduce the taxes on land, and to abolish or absorb those that were of an objectionable nature.

The efforts that were made by several of our earlier administrators to afford relief to the exhausted districts under their control by means of rough surveys, reduction of assessment, and other expedients, were productive of great benefit in their several localities, and pointed the way towards a more general measure.

The first and main object in setting on foot a ryotwar system of survey, was to determine the size of the plots of ground or fields, to form the unit or basis of the survey, and on which the cess should be placed. It is evident that no object can be attained by fixing this area at less than can be cultivated by ryots of the most limited means. The smallest amount of stock that can be cultivated with, is one pair of bullocks; with one bullock only, a ryot cannot cultivate at all, and he must either borrow another bullock or throw up his land. The *minimum* area to be measured separately and to be constituted a "Number," as it is called, was fixed therefore by the new survey at what two bullocks could plough. In determining the *maximum* area to be measured by the survey and constituted a separate "Number," it is manifest that this must not exceed the means of the generality of the ryots to cultivate, so that they may be easily made the subject of sale and transfer. Cultivators possessing two pairs of bullocks were found on enquiry to form the most numerous class of small farmers, and the *maximum* area was consequently fixed at what four bullocks could plough.

It was finally determined therefore to fix the size of Revenue Survey Numbers at from what one pair of bullocks could plough up to double that size. On an examination of the internal distribution of the village lands with a view to adjust them to this size, they were found to consist of recognized sub-divisions known as *thuls*, *tickas*, *daghs*, &c. These were generally found to be too large for our purpose, being held for the most part by several individuals. The external limits of these were usually permanent, but the interior limits were constantly changing among the occupants through the operation of sales, transfer, and inheritance, and were found to be broken up in many instances into very minute portions. For adapting the above rule for the measurements of these plots or fields to "Survey Numbers," it was resolved to interfere as little as possible with the existing limits of fields or occupancies; and the following rules for the division of land were finally sanctioned for this purpose:—

1*st*. The size of Revenue Survey Numbers, will as a rule be from what a single pair of bullocks can plough up to double this quantity.

2*nd*. Tracts of land incapable of, or unsuitable for, cultivation, may be divided into as large portions as may be convenient.

3*rd*. Land held on different tenures must be measured separately and not included on the same Number.

4*th*. Different kinds of culture—as dry crop, rice, garden, &c., when in conformity with the usage of the districts—should as far as practicable be measured into separate Numbers.

5*th*. Every holding* falling within the limits prescribed by Rule 1, should be constituted a Survey Number.

6*th*. Every holding in excess of this area, should be divided into two or more Numbers, so as to bring the area of each within the rule.

7*th*. When a holding is of less area than is laid down in Rule 1, and there are other similar holdings contiguous to it, on the same tenure, so

* By "holding" is meant any field, estate or coparcenery, contained within a continuous line of boundary and in the possession of one person or coparcenery.

communication made. This will cause little delay to the traffic (unless the break is several miles long) when the train can be shunted on to its own line at the point where both are perfect. Every train must be brought to a stand before advancing on the single portion, and not allowed to cross unless a pilot is on the engine, as is the custom with ordinary passenger, or other trains when from some cause or other one line has been disabled and is undergoing repairs.

But in the case of a single line, it will be necessary to obtain the required materials from the most convenient sidings, being careful only to carry away what is absolutely wanting.

It would save considerable labor if each pair of rails could be transported with sleepers, chairs and keys, *en masse*, only unfixing the fishes, where used; but whether this could be done must depend on the available power and carriage.

The weight of one set complete, or element (*ut ita dicam*) would be, approximately, slightly under two tons (varying with every Railway) which might be raised, carried for a short distance, and placed in position, by 30 men. When this is done, the ballast must receive an additional amount of previous care. In all cases the services of the regular plate-layers and navvies employed on the line should, if possible, be obtained.

R. A. S.

VENTILATION AND COOLING*

In 1862, as our readers are probably aware, a Royal Commission was constituted in England, to Report on the state and defects of the Barrack and Hospital accommodation provided for the army, and to suggest measures for its improvement. Its Report was presented in the following year; and in 1864 a Supplementary Report was issued, containing suggestions for the Sanitary improvement of Indian stations, with special reference to the construction of Barracks and Hospitals in tropical climates. In 1863, the Government of India appointed Lieut.-Colonel W. A. Crommelin, C.B., R.E., an officer of much Civil and Military experience, to take up the matter locally, and with special attention to Indian requirements, and the important resolution of the Governor General in Council in the P. W. Department, dated 16th December, 1864, gives the final result of that Officer's labors for the last two years.

Although, however, the details of arrangement and construction of Barracks and Hospitals were thus practically settled after very full discussion, it was felt that the question of Ventilating and Cooling Barracks and other public buildings in India might, with advantage, be considered by a separate Committee, which was duly constituted at Roorkee in 1865; and their First Report has lately been presented. Although it is chiefly occupied by preliminary discussions necessary to clear the ground for useful results being arrived at, it sufficiently indicates the probable issue of the enquiry to make it worth while to state briefly the difficulties attending the

* First Report of the Committee on Ventilation and Cooling of Public Buildings in India. Roorkee, 1866.

subject, and the points to which inventors' attention should be directed in their endeavour to solve those difficulties.

The Ventilation of buildings in cold or temperate climates, depends on the fact of the air inside a building being warmer and therefore lighter than the external air. If holes are left in the upper part of a room, the foul air will pass out of them and fresh air can come in through the windows or otherwise. If more powerful means are required, then regular ventilating shafts are provided, by one set of which the cold air comes in, and by the other set the foul air escapes. The up-cast and down-cast shafts of mines are arranged as is well known on this principle, and half the modern public buildings are ventilated in the same way—the heat of a fire or gas being used in the up-shafts to create a strong draft.

But in a great part of India, the temperature of the external air is very much higher than that inside a building, and that often for months together, and by night as well as by day. This fact appears to have been lost sight of by the London Commissioners on Tropical Barracks, their most important recommendations being evidently adapted only to a West Indian climate, or the climate of India near the sea-coast, and not to Upper India and its hot winds at all. Indeed, they acknowledge the difficulties on this point, and recommend its being locally taken up, as it has been. It is evident, from a little consideration, that the above fact prevents anything like self-acting ventilation, for doors and windows must be shut to exclude the hot air, while the foul air inside being cooler and therefore heavier, will not of its own accord pass out of openings above. To effect the admission of the one and the exit of the other, it will be necessary to create a powerful artificial draft.

But for some portion of the hot weather (as said above) it is necessary to cool the air previous to admitting it, and the two questions have to a certain extent to be considered together. What is now done, as is well known, is either to keep doors and windows shut all day long, an unhealthy practice where a number of men are in the same building, or to put a *tattie*, or grass screen in the doorways to windward, keep it wetted, and thus cool the hot air as it passes throught it—the temperature being lowered in this manner from 5° to 20°, varying with the heat and dryness of the blast.

The defects of this practice are several,—unless there is a strong wind blowing, very little air comes in through the *tattie*,—and if the wind *is* strong, it passes into the room in cold damp blasts, unhealthy to those who are near it, while at the further end of the room it may be scarcely felt. Unless the *tattie* is kept constantly wet, of course hot air, instead of cold, is drawn in, and it is difficult to keep the *tattie* properly wet by hand-labor alone. Moreover, the arrangement is only effective on the windward side of the building; the rooms to leeward must remain hot. The vegetable matter of the *tattie* under the constant influence of heat and moisture is also apt to decompose, and render the permeating air unwholesome.

Attempts have been made to remedy these evils. Grant's trough apparatus ensures a more equable watering of the tattie—and thermantidotes, consisting of an arrangement of blowers turning on a horizontal axle, and driven by hand or bullock-power, are used to create a blast when the wind is not blowing. There still remains however the fitful character of the blast, and the want of any means of diffusing it equably.

It may be as well here to note in passing, that Punkahs merely agitate the hot air inside, and though rendering it for the moment cool to those under or near them, do not at all lower the general temperature of a room, nor do they help at all in ventilating it. We shall speak of their arrangement presently,—but their expense and inconvenience make it very desirable to supersede them altogether, if possible.

More than one scheme has been proposed for cooling the air without the aid of the tattie, and it is possible that some of these may be effectual, but inventors are apt to forget the large quantity of cool air required—and the expense attending the arrangement. Nor will a complicated apparatus do for a country where unskilled workmen are alone available to repair it when anything goes wrong. One inventor, for instance, proposes to force the air through ice, but makes no calculation of the enormous expense to be incurred in making the ice. A more feasible proposal is that of Professor Piazzi Smith, viz., to force the air through a worm like that of a still, surrounded by cold water; the air when thus cooled to be distributed as required—but the power required to overcome the great friction of the hollow tubes, and to provide an adequate supply of air, seems to be have been under-rated; a scheme on the same principle as this, but differing in detail, is still under consideration. Of the various kind of blowers, other than the ordinary thermantidote, which have been tried or suggested, Arnott's Hydrostatic Pump is the only one that promises well, and seems at all likely to succeed.

From all the discussion that has taken place, and with the numerous projects submitted, the results at present attained appear to be these:—

1st. That no arrangement as yet hit upon for cooling the air is better than the grass tattie; and that some better means for watering it is still desirable.

2nd. That during the rainy season it is not necessary to cool the air artificially, but simply to blow in a proper quantity of it.

3rd. That as a blower, nothing has yet appeared,* preferable to one or other of the forms of the ordinary thermantidote, driven by coolies or bullocks, or in particular places by steam power.

4th. That the amount of fresh air required has been estimated by the English Commission as 20 cubic feet per man per minute, and this may be taken as the standard. The provision for any particular building therefore, is a simple matter of calculation, depending on its size, number of inmates, number of thermantidotes used, and the speed at which they are driven.

5th. That the proper mode of diffusing the fresh air is still an open question; probably it should be by flues from the thermantidote chamber, but whether under the floor or round the sides of the room; whether one or two large inlets will be best for a room; or

* Unless Arnott's pump on the gasometer principle, which is still under trial, should prove effective and economical.

whether a number of small inlets is preferable, are still undecided points, and can only be settled by experiment.

6th. That from recent experiments which have been made, the position (as regards height) of the outlets for foul air is a matter of indifference. It will be forced out, wherever the exits are placed, if a proper supply of fresh air is forced in.

If it should eventually turn out, that in many buildings at any rate, Punkahs cannot be dispensed with, the best mode of pulling them with due regard to efficiency and economy has still to be decided. Grant's system of treadles, which promised well at first, seems latterly to have failed. Rotary punkahs have been several times proposed and rejected, and schemes of pulling punkahs by clockwork—by pendulums—and by falling weights, seem as yet not to have passed out of the regions of theory. It seems generally admitted now, that the old broad punkahs with short light fringes are far less effective than narrow punkahs with deep heavy fringes; and if their number is properly accomodated to the size of the room—and the pulling power to the number to be pulled—and if they are carefully hung, it does not seem likely from such evidence as has yet appeared, that the present arrangement will be in principle superseded.

The above remarks on an important question may be of use to many whose attention has been, and is now turned in this direction, as serving to show how the question at present stands, and what more is wanted. It is quite possible, however, that they may be modified by the time the next Report of the Ventilation Committee may be presented, and they are merely an expression of individual views.

J. G. M.

No. CXI.

THE ADEN TANKS.

Compiled from an account of Aden by CAPTAIN PLAYFAIR, *and from Official Records, by* LIEUT. S. S. JACOB, *Assist. Engineer.*

THE scarcity of water supply must always have been a cause of anxiety to those who have from time to time inhabited Aden. Water of a good quality, but in limited quantities, is found at the head of valleys within the crater and to the west of the town; as the wells approach the sea, they become more and more brackish, and those within the town are unfit for any purpose save ablution. These are in number about 150, of which perhaps 50 are potable, and yield an aggregate quantity of about 15,000 gallons per diem. They are sunk often in the solid rock to a depth of from 120 to 185 feet, and in the best one, the water stands at a depth of 70 feet below the sea level. An abundant supply of water is procurable on the northern side of the harbour but the difficulty of bringing it into Aden and its liability to be cut off by hostile Arabs, have hitherto rendered it almost unavailable. So great has been the demand, that the brackish water brought from Sheik Othman, a village five miles distant, has often been sold to the shipping and others, for as much as Rs. 8 per 100 gallons.

A project for bringing fresh water from the interior by an aqueduct is now under the consideration of Government.

It was doubtless the want of this common necessary of life which induced the first inhabitants to provide some means of storing supplies of water, and the features of the rocks were well adapted to suggest the construction of Reservoirs or Tanks.

In the centre of the Peninsula of Aden is a range of hills, which rises most 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 rapidly carried to the sea by means of long narrow valleys. On the interior or eastern side the hills are quite as abrupt, but the descent is broken by a large table land occurring midway between the summit and the sea level, which occupies about one-fifth of the entire superficies of Aden. This plateau is intersected by numerous ravines, nearly all of which converge into one valley, which thus receives a large portion of the drainage of the peninsula. The steepness of the hills, the hardness of the rocks, and the scanty soil upon them, all combine to prevent any great amount of absorption; and thus a moderate fall of rain suffices to send a stupendous torrent of water down the valley, which ere it reaches the sea not unfrequently attains the proportions of a river.

To collect and store this water the Reservoirs were constructed. They are extremely fantastic in their shapes; some are formed by a dyke being built across the gorge of a valley; in others the soil in front of a re-entering angle in 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 masonry channels to ensure no water being lost. The overflow of one tank has been conducted into the succeeding one, and thus a complete chain has been formed.

There is a tradition in Aden, that about A. H. 906 (A. D. 1500) the individual who was then Governor persevered in digging wells for sweet water, and being successful the reservoirs were permitted to fall to ruins, or to be filled up with the débris washed down from the hills, which would be sure to happen sooner or later, as there were no shield bunds; and in 1859, when the tanks were in process of restoration, although the channel had been cleared for about a quarter of a mile above the upper tank, a storm which occurred brought down such a large deposit of stones and gravel, that Captain Fuller in 1860 constructed shield bunds across the necks of the water-courses leading to the tanks. Below the shield bunds, and in addition to them across the main ravine, are two bunds which form lakes, and these are connected with the tanks below, by pipes which can be shut off when necessary.

In the shield bunds are inserted grated sluices 2 feet square, to allow water to pass when it rains but slightly, and before it has time to be absorbed by the rock.

In 1854, Captain Playfair, Assistant to the Political Resident, turned his attention to these tanks, and on his own responsibility undertook the task of restoring them; the expense being met by the Municipal Fund, and by the money realized by the sale of water. A few ruined tanks on the sides of the hills which never were buried or concealed, were the only visible remains of the ancient reservoirs; but as the work progressed, the magnitude of the system became apparent, and a further measure of assistance was afforded to Captain Playfair by the quit rents charged on building grants, being appropriated to the object.

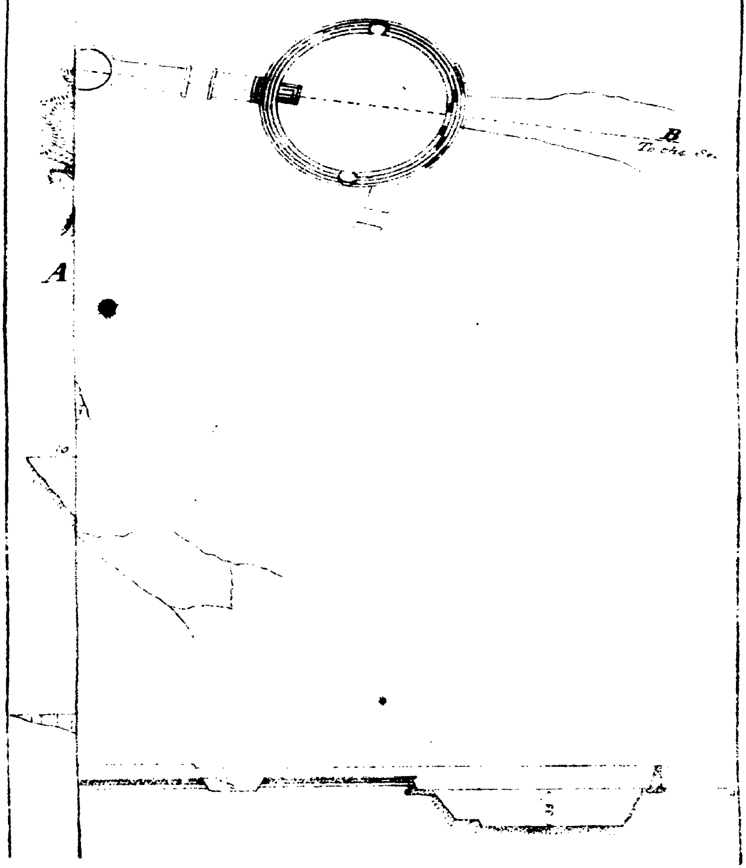
Subsequently, at the request of Brigadier Coghlan, then Political Resident at Aden, Government granted such sums of money as from time to time were required to carry on the restoration without further reference. Each month, as further excavations were made, and the débris with which they were filled was removed, new tanks came to view, and so the work progressed under the Superintendence of Captain Playfair till February 1857, when illness compelled him to return to Europe, and the work was made over to the Executive Engineer, Aden. Up to that time, tanks had been completed, the aggregate capacity of which amounted to about 3,538,000 gallons, and the expense incurred in effecting this, amounted to no more than Rs. 11,542, of which Rs. 6,500 had been granted by Government.

Subsequently, when a violent fall of rain had afforded the necessary experience regarding the style of work required, and the size of the aqueduct necessary to carry of the overflow of No. 1 Tank; Captain Playfair's aqueduct was replaced by one better adapted to resist the immense force exerted by the stream; the walls of the tanks repaired and cleared out by him were also heightened so as to double their capacity, and one tank was greatly increased by using it as a quarry for stone required in the work.

The plan will show the position of the tanks with reference to each other, and the sections will show the depths on the section line; but the bottom of each tank presents more or less an irregular, fantastic appearance, according as the natural surface of the rock has been plastered over, or masonry has been used.

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 supply the next tank, until the whole system is full; and when the last, a large circular

THE ADEN TANKS.



tank, has received its supply, the surplus water is carried to the sea by a channel 60 feet wide, the sides of which are dry rubble (slope 1 to 1) with a masonry coping; and across it at every 30 feet masonry bunds are placed below the surface to protect the bed from scouring.

The plan on which the last, the circular tank, has been constructed is worthy of note; it is built in a series of rings or off-sets, increasing in diameter from the bottom upwards; the perpendicular distance between each off-set is about 5 feet, and the off-set itself about 1 foot in width. There are two places where these off-sets have been omitted to facilitate the drawing of water; over each a pulley can be arranged for hoisting the bucket. The advantage of these off-sets is the facility with which it enabled men in the first instance to construct the tank and afterwards to effect repairs.

All the tanks are furnished with flights of small steps constructed on the sides wherever necessary or convenient.

Perhaps it may prove useful to state the manner in which these tanks have been plastered. Whenever any uncertainty existed as to the nature of the ground, it was roughly paved, leaving joints of about 1 inch width; this lessens the chance of crevices occurring between the stones which might sometimes occur if they were set close. On this, concrete composed of equal parts of lime and gravel was well rammed. The thickness of concrete depends upon the height from which the water had to fall; about 1 foot in thickness of concrete for 10 feet fall is sufficient. Over this, 3 inches rough casting (composed of 1 part chunam, 1 part sand, and 4 lbs. hemp, per 100 square feet, well mixed) is laid in layers of about 1 inch at a time; and when the rammer emits a clear hard sound, the final coat of plaster is added, composed of 10 parts chunam and 1 part sand.

The lime at Aden is obtained from coral, and is of good quality. Care should be taken to prevent heavy rain from falling on the plaster until it has properly set, and it should also be shaded from the sun in the hot weather.

The total contents of the Government tanks, including upper lakes formed by bunds, are about 11,000,000 gallons. A moderate fall of rain, say about 3 inches in 3 hours, would fill the whole system, and in a few times would repay Government well for all outlay incurred: but unfortunately we have had so little rain in Aden since the tanks have been completed, that it is not fair to draw conclusions. Every shower of rain saves Government so many rupees, and gives the troops and others at Aden the blessings of good sweet water. Hitherto the water collected, owing to the scarcity of rain, has not proved anything like sufficient.

S. S. J.

No. CXII.

ROADS IN COORG.

Abridged from a Report by MAJOR R. H. SANKEY, R.E., *Assistant to the Chief Engineer, Mysore.*

IN 1862 a small platform bridge 9 feet wide by 4 feet high, placed in one of the numerous short embankments on the Mercara-Veerajendrapett road in Coorg was carried away by a flood, and the Engineer, Mr. Stoddard, submitted an estimate amounting to Rs. 2,110, for reconstructing the work, increasing the bridge to a span of 12 feet, and raising the embankment throughout—making, in fact, apparently all reasonable provision for meeting the requirements of the highest probable flood.

But the floods of 1863, proved much more serious than had been anticipated, and a second design had to be framed, for a bridge of double the capacity. Last year's floods coming down with still greater power, and further the labor rate having sensibly increased, a third revision was found essential, bringing the estimate up to Rs. 14,960, or seven times the amount originally contemplated.

Viewing the whole circumstances of this case, and others bearing a close analogy to it, the Chief Engineer considered a strict enquiry on the spot essential, and with this object I proceeded to Coorg on the 19th ultimo. Having now carefully inspected the works in question, I am clearly of opinion that the Executive Engineer has acted with all reasonable foresight, in framing his successive estimates, with the data of previous floods before him, but that from the daily changes now being wrought, in the physical condition of Coorg, these data cannot be accepted as guides to the future.

In the former condition of the country, when dense rolling forest covered all but the mountain tops and the rice lands in the deep intervening valleys, the rain-fall was in part sucked up by the redundant vegetation, in part absorbed into the earth—being stopped from flowing off by thickly interlacing roots—in part evaporated from countless leaves and stems, and only probably a comparatively small portion, enabled to flow off at once into the various streams. It appears to me however, that in consequence of the great areas of forest land, now laid bare yearly by the planter, the rain-fall is discharged much more rapidly down the mountain slopes than was formerly the case, among other results giving rise to floods of yearly increasing magnitude. That such must necessarily be the result of extensive clearings, would I should think be at once admitted. I shall give hereafter certain proofs that at least the argument does not rest on theory—meanwhile the mere statement of the fact, in reference to a country with the known heavy* rain-fall of Coorg, must give rise to vague apprehensions for the future.

The consideration of the general question, as to the effects of clearings in other tracts as well as Coorg, on the bridges, anicuts, and other river works, down to the sea, though naturally following, is much beyond my powers and present object, I trust however I may be excused for deeming it of sufficient importance, even in the limited sense of its direct effect on Coorg works, to warrant my converting what was originally intended as a simple professional report on two or three individual works, into one of a more general nature, relating to the present position of the Department and the work before it, under the peculiar circumstances above described.

The present time also appears for other reasons, suitable to such a consideration of our position. It was not till three years after the British had possessed themselves of the country, that the impossibility of moving a force into South Coorg—to subdue the rebellion which had there sprung up (1837)—demonstrated the absolute necessity of constructing some kind of Military road, and the Sumpagee ghaut was made by Lieutenant Fast of the Engineers. The Anachowkoor road and Periambady ghaut were finished some twelve years later, also as a military necessity—the old line to Cannanore, through Wynaad and by the Perriah pass, proving altogether impracticable. The connecting road between Mercara and Veera-

* Rain-fall at Mercara—1863-64, 135 inches; 1864-65, 143 inches. It is believed to be much heavier at Periambady ghaut.

jendrapett, with a similar military object, was made shortly afterwards. At this moment these three military roads, remain practically the* only ones devoted to wheeled vehicles in the country, and it will be seen from what follows that even these—masterpieces of engineering as they were, when first driven through almost impenetrable forests—are in many places quite unsuited to the requirements of the cart traffic which has now set in upon them, and which with the altered physical conditions above alluded to, coupled with other causes, threatens to render them entirely unserviceable, unless energetic measures be adopted for their preservation, and reconstruction in places. When in addition to this it is borne in mind, that hardly a portion of Coorg, with the exception of Nalknad, remains unoccupied by planters, there can be no reasonable doubt that the whole country will be the scene of European enterprise, in a very short period—Coorg in fact forming with Monzerabad on the north, and Wynaad on the south, a vast connected colony. It therefore appears to me perfectly clear, that even were the main roads above alluded to, in thorough working order, they would only in a very partial degree, meet the first wants of the country, and that an imperative necessity exists for devising some practical means of giving a more extended series of communication.

To facilitate reference I have constructed the accompanying Map, from such information as I could procure. The Trigonometrical Survey shows only the old native tracks, and it may be doubted whether the topographical features are very correctly indicated. We have no actual surveys of the Ghaut Roads; they are however here I think sufficiently well laid down, to answer my present object. The heights above sea level have been determined from means, struck on the observations of the Rev. Mr. Richter, Mr. Stoddard, and myself; being however taken with the Aneroid, they can only be accepted as approximations.

With reference to the condition of the Ghaut roads, in regard to gradient and soil, I would invite attention to the longitudinal sections herewith given. Though the slopes have been roughly determined, without the use of the instrument, they will be found sufficiently accurate for all practical purposes, and show at a glance the weak points claiming early attention.

First in the list is the Mercara-Fraserpett road, 19 miles. This is

* Carts, it is true, have passed over the new Mercara-Codlipett road, but the work is far from complete.

probably the most defectively traced line in the country, for it will be noted that although there is only about 1,000 feet difference in level between the termini (giving an average fall of 1 in 100), there are two places between the 3rd and 5th miles, with gradients of 1 in 9, and 1 in 10, and many others with 1 in 15 and 16. The present condition of the steepest portion is most distressing. The longitudinal slopes being as great or greater than the side slopes, the water tears down the centre of the road, ripping up everything but large boulders, and the surface repairs, made from the trifling maintenance allowance, Rs. 150 per mile, are altogether useless.

The Coorg hills being composed of metamorphic rock in which felspar is largely present, all near the surface is decayed, and there is very little really good gravel to be procured. Good gravel indeed appears only to be met with in laterite formations, at a few points along the Tulla Cauvery road; also between Veerajendrapett and Periambady, and again on the Bittengall road with perhaps a few other isolated spots. Metal is procurable either by blasting, or from the embedded boulders met with in excavating the scarps. While therefore presenting great facilities for first formation, it is evident that very serious evils result from the geological structure of Coorg, in regard to two of the main requisites of ghaut roads. The first is, that the foundation of the road must be soft and yielding, and that there is no proper top dressing present, for such metalling as may be laid down; the second, that the side scarps and other portions readily yield, and fall away with the slightest run of water on the surface—there in fact being no coherence in the soil.

To my mind therefore, a new trace of at least all portions, with gradients above 1 in 18 is a first necessity. The portion between Mercara and Sonticoopa being the worst, I would urge an entirely new line being made. Without a more careful examination of the country, trial traces, levels, &c., it would of course be quite impossible to say what actual line should be adopted, I am however satisfied that on all professional grounds, as also from the stringent orders issued by the Government of India, in regard to gradients of ghaut roads, (the maximum having been expressly limited to 1 in 22,) no other conclusion can be arrived at, than a thorough reconstruction, for the upper portion of this road. Between Sonticoopa and Fraserpett, it will also be observed, that there are in places, very objectionable gradients. The adoption of zig-zags, or a slightly more

circuitous route in one or two places, amounting in the whole, to (say) a reconstruction of 3 miles, should I imagine, suffice. I would also observe that in addition to other objectionable features, high jungle lines the road closely for several miles, chiefly in its lower portions, and if not removed at once by planters (the undergrowth being left to preserve the surface) should be cut down to 15 yards on either side of the road. Halting places for carts and cattle off the road should be provided, and stringent regulations enforced regarding their use.

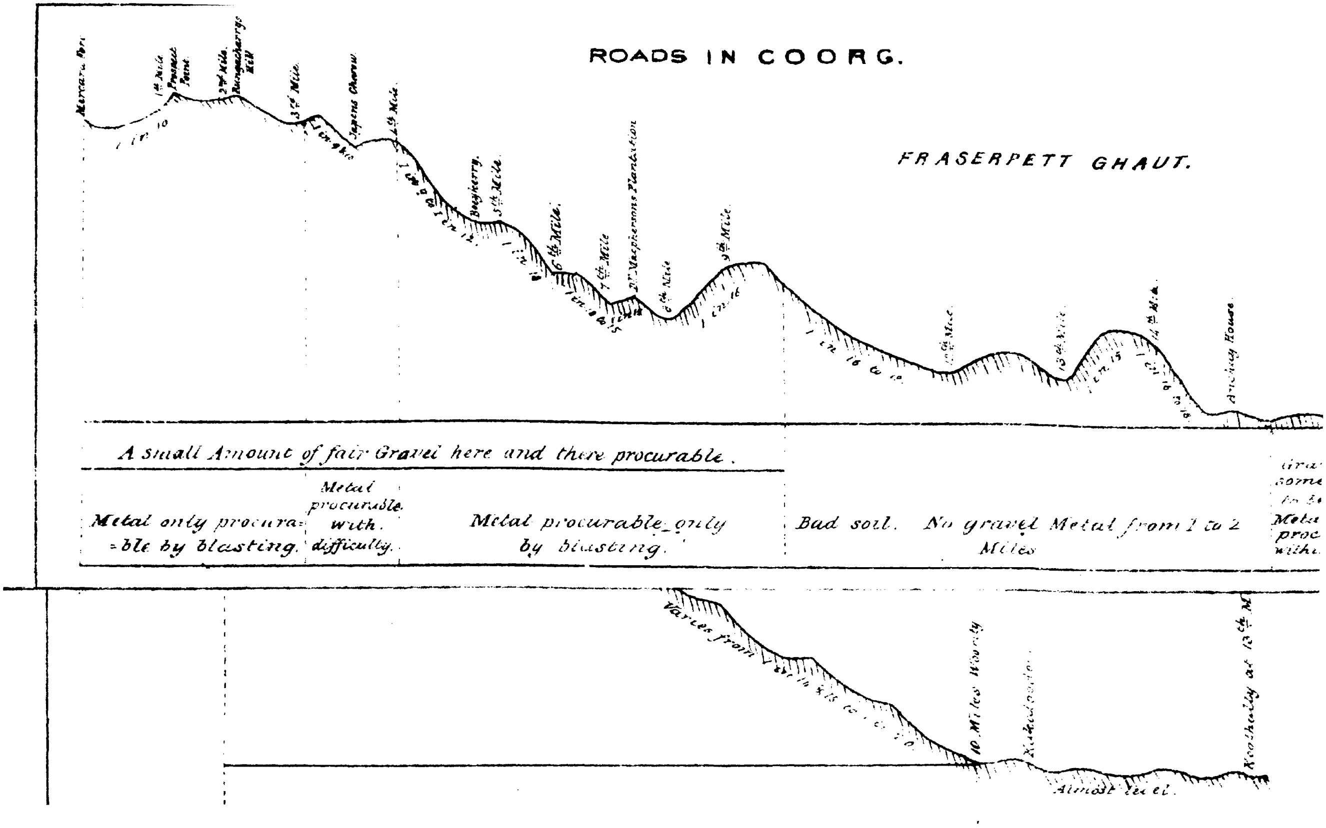
The Sumpagee Ghaut, 19¼ miles in length, and leading direct to Mangalore, is the next line claiming attention. This great work, the first of the 14 or 15 roads now carried through the Western ghauts, is undoubtedly the best in Coorg, and so far as I can judge only requires trifling rectification between the 9th and 10th miles. At the upper portion of the mile the slope is 1 in 12, and for a short distance approaching a bridge over a ravine, at the 10th mile, as much as 1 in 6 or 7. There is a deep narrow gorge at this point, which no doubt rendered the selection of a better line almost impossible, with the features of the neighbouring slopes, shrouded in dense forest. Even now with nearly all laid bare, it is no easy matter to choose another, and although from my own personal examination, I am satisfied the line can be carried by a zig-zag in another direction, very careful alignment will be required. At a rough estimation, I should say 2½ miles of new ghaut would have to be made. It will be observed that from about the 2½ to the 4th mile, there is a counter gradient; this however was essential, in order to get over the saddle on one of the lower spurs of the range, running off towards Tulla Cauvery. The ghaut is nearly metalled throughout, indeed I might say paved, in its lower portion. The metal is staring and gritty, and I should fear would in great measure be swept away, if means cannot be found before next May, for protecting it with gravel, and a well formed up roadway.

Several slips have occurred in this line, the most serious one being below the 10th mile stone. This resulted in a great measure from the clearings both above and below the roadway, and though a passable road has been constructed across the breach, some permanent arrangement must be made for diverting the upper drainage, and leading it off to the stream below. The side cuttings in the first mile near Mercara are extremely heavy, one double escarpment being about 90 feet high, and the drop on the lower side of the road precipitous to a degree. Some thick growth should be encouraged here to obviate all possibility of a slip which, if it occurred, would be fraught with the most serious consequences. Halting places for carts are also required on this ghaut.

The total fall in the first 15 miles of this Ghaut is about 2,900 feet, which gives 1 in 37 for the whole line, but it will be observed that the influence of the counterslope has prevented this being worked out. From the foot of the ghaut to the town of Sumpagee, 4½ miles, the fall is only about 55 feet.

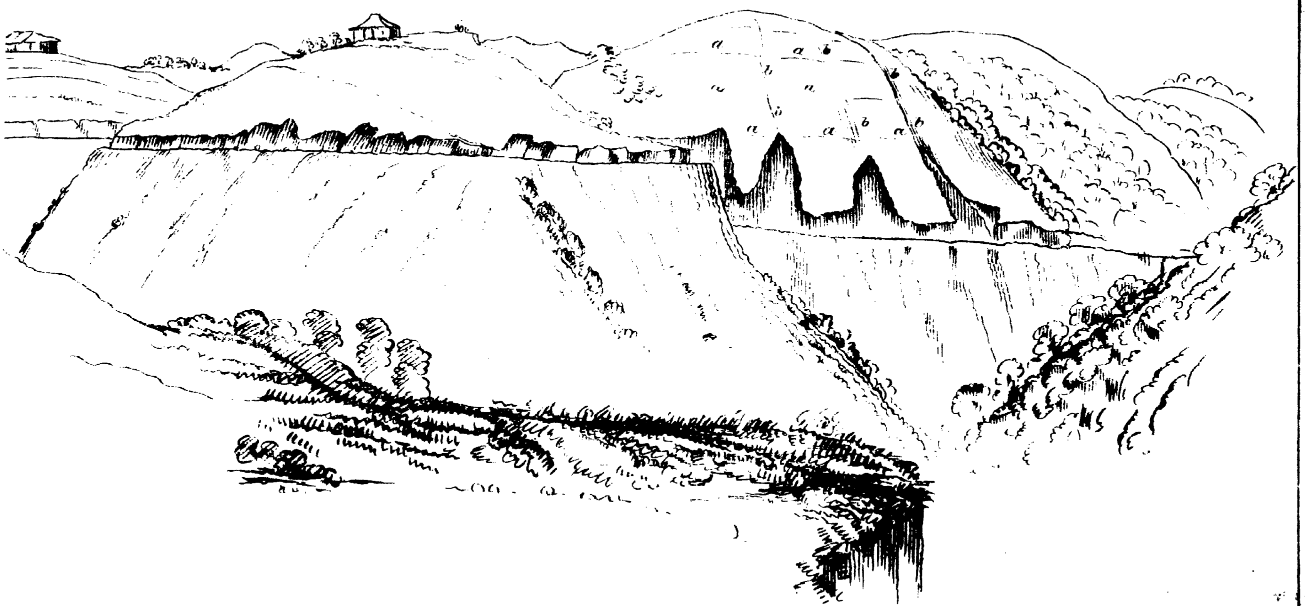
The next Ghaut in order of succession, is the first 2½ miles of the road leading out of Mercara, towards Veerajendrapett. At the end of the 1st mile and after passing the second, the gradients are 1 in 9, and in nearly all other portions excessively severe, so much so indeed that I would beg to recommend entire reconstruction. The side cuttings in the upper portion are also extremely heavy, and as this part perhaps afford the most marked example of the effects of clearings above ghaut roads, I herewith attach a rough sketch which I made of the first mile of this ghaut, as seen from the Sumpagee. Here it will be observed on the central hill, that the planter, to prevent the soil being washed away from his trees, ran the horizontal drains *a*, *a*, *a*, *a*, *a*, but these becoming surcharged, burst at different points, forming the perpendicular channels *b*, *b*, *b*, *b*, at the end of each of which, most formidable breaches have occurred. These four slips in this short space are each I should say at least 100 feet high. On their occurrence it took several days with the utmost exertions to clear the road, and in two cases the breaches carried away the roadway itself, occasioning the most formidable chasms on the lower side. My own opinion is that unless some thick growth be at once encouraged on this hill, the next monsoon will see these breaches greatly extended. In fact, there appears every likelihood of the original form of the hill being altered, and the work, in preserving the road, becoming endless.

As a distinct proof that to upper clearings, are to be attributed nearly all the serious slips which have taken place, I would point to the present condition of the cutting mentioned above, as also to the weathered, and apparently perfectly safe condition of many other similar scarps, where the upper surface of the hill has not been disturbed. Every one passing through Coorg, has been struck with the gigantic trenches, carried through deep valleys, and along the tops of the highest hills, serving as ancient boundary marks (Kodungas). Some of these are nearly 40 feet from


ROADS IN COORG.
FRASERPETT GHAUT.
Mercara Fort
1st Mile Prospect Point.
2nd Mile Rungacharrys Hill
3rd Mile
Japens Cherow
4th Mile
Boyjkerry.
5th Mile
6th Mile
7th Mile
Dr. Macphersons Plantation
9th Mile
Arching House
A small Amount of fair Gravel here and there procurable.
Metal only procurable by blasting.
Metal procurable with difficulty.
Metal procurable only by blasting.
Bad soil. No gravel Metal from 1 to 2 Miles
10 Miles Woorily
Koothully at 13th M
Almost level.

PUBLIC WORKS IN COORG.

NAWAB SALAR JUNG BAHADUR.



summit to bottom of ditch, and often taken along hill sides with an angle of 80° to the horizon; yet though hundreds of years old, the edges of most of them are as sharp as possible, in spite of the natural incoherence of the soil. This simply results from the surface not having been ever disturbed.

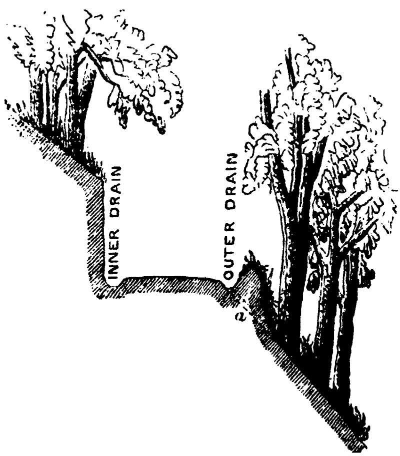
The total fall in this ghaut is about 550 feet in 2½ miles, giving 1 in 24 over all; there are however two short counterslopes, which have thrown out the remaining gradients.

The fourth and last of what may more especially be termed, Ghaut roads in Coorg, is that at Periambady—10 miles in length—leading down towards Cannanore. It will be observed from the section, that for the first 2¼ miles the slope is sufficiently gentle, but for the three-quarters of a mile just above the Wotacolly bridge, there is a distressing gradient of 1 in 10 and 12. The road after this is easy and level in places to beyond the 4th mile, from which it drops down to Woority with generally far too steep a gradient.

I have very little doubt, that by carrying the line along the southern slopes of the hill at Wotacolly, 1½ or at most 2 miles of new ghaut would overcome the objectionable gradient above the bridge. Now that the hill sides have been laid bare and planted, it is easy to see that an alternative line lies in this direction; but when Captain Francis laid out the ghaut, so dense was the undergrowth and vast the forest overhead, that no neighbouring feature of the country could be seen from below. It was only in fact by lighting fires along the trace and standing on a bare topped mountain, commanding the ghaut, that the direction with reference to the adjoining ground could be ascertained. The alteration of the lower portion of the ghaut is a different matter. Though undoubtedy desirable, it is not easy to see how it could be effected. The point on the section, named the Jemadar's rock, is, so far as I can judge, the top of a precipice of sheet rock, across the face of which it having been found impossible to work, it was allowed to rule the gradient down to Woority. Once this point was accepted, I conclude there was nothing for it but to lay out the ghaut as it now exists; the hill side, along which it is carried, being at far too steep a slope to allow of length being gained by a zig-zag.

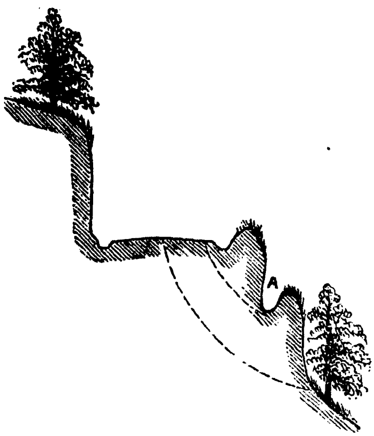
I found the upper portion of the ghaut, where the gradients are easy, all in fair enough trafficable condition and being metalled, but the evils of too steep a gradient were at once apparent lower down. Previous to the ghaut roads being taken over by this Department in 1862, the Madras Government had spent some Rs. 60,000 in metalling this line, but chiefly from steepness of gradient, the metal (unfortunately very thinly laid on, and placed on an imperfectly barrelled road) was almost wholly swept away, and only traces of it can here and there be observed. In the first rough shaping of the ghaut, many boulders had been left, and others of a smaller size were probably thrown in from time to time, to fill up the deep channels cut by the water tearing down the ghaut; its dreadful condition can therefore hardly be exaggerated.

In speaking of the Veerajendrapett Ghaut, I have shown the effects of clearings above hill side scarps. The portion of this (the Periambady) Ghaut already cleared, showed in many places on the other hand, the evils of clearing on the lower side of the road, where the side slopes are great. When forming the original roadway, Captain Francis adopted a simple barrelled surface as in ordinary roads, thus throwing half the drainage over the hill sides, by small cuts (*a*) from the outer drain at every 30 or 40 feet, as roughly shown in the side section. The plan answered admirably in the former uncleared state of the hill sides, fewer cross drains being found necessary, and the thick vegetation on the outer slopes preventing the chance of the soil being washed away and breaches resulting. The moment however the slopes were cleared of jungle, the whole condition of matters changed.



The planter to prevent the soil being washed from the lower slopes, very naturally cut the longitudinal drain A, in the next section. This unfortunately operating in undermining the bank, frequent breaches of the nature shown by the dotted lines, have been produced.

The Executive Engineer, to help out matters as much as he could, has been endeavouring to dispense altogether with the outer drain, by raising the outer side of the road, and throwing the whole drainage into the inner drain, which having thus double its previous work to do, required to be eased by new cross drains at closer intervals; 52 extra cross drains are therefore now in the course of construction, but the attendant difficulties are of a very serious character. To obtain an outfall for these drains, which shall be free from the chances of occasioning frequent breaches, seems very nearly an impossibility where the hill side is laid bare, and unless very thick planting can be maintained down the side of the channels, I do not see how the matter can be managed.



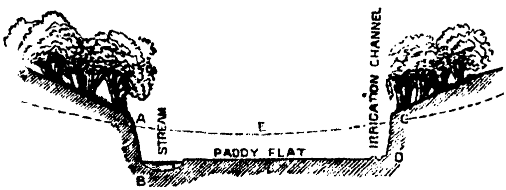
For all existing uncleared ground along ghaut roads, I would venture strongly to urge the necessity, of preserving a belt of low jungle, both on the upper and lower slopes, of from 40 to 50 yards wide. Indeed to ordinary observers, it would appear to be quite as little in the interests of the planter, as of Government, to cultivate slopes which are so steep that the upper mould is easily washed off, and where, as is not unfrequently the case, such slips occur that plants and all are washed into the valley below. Hill sides are now planted at angles of 45°, 50°, and even 60° to the horizon, when it would hardly appear possible to preserve for any length of time, the surface soil on slopes of more that 20°. I am informed that it is the practice on steep slopes, to plant the coffee trees closer together, but in any case the ground between must be kept clean and free from weeds, so that the evil is only very slightly mitigated.

There are now about 7 miles of the Periambady ghaut to which my remarks especially refer, as the forest is as yet standing, and it is with regard to this I should be glad to see some decision arrived at. The slopes are extremely steep for the last 6 miles of the ghaut, and all along may be observed the noblest spars of Poon (*Calophyllum bracteatum*), Anjely (*Artocarpus hersuta*), Chittagong wood (*Cickrassia tabularis*), Honay (*Pterocarpus marsupea*), Sumpengi (*Michelia champeca*), Red Cedar (*Cedrela toona*), and many other timbers, whose value on the coast is I understand rising daily, and which therefore, it would appear most desirable to conserve.

Having described at more or less length, the ghaut portions of the through main lines of communication, I would beg to draw attention to the two connecting links, viz. the road from the foot of the Veerajendrapett ghaut to Periambady—21½ miles—and that from Periambady through Attoor and Tittamutty, leading towards Mysore—39½ miles to the frontier.

As both these lines partake very much of the same characteristics, I may at once state, that they are a perpetual series of rises and falls, being carried across low spurs of hills, with intervening paddy flats. The gradients are frequently very bad indeed, but being for the most part over short pieces, I would not suggest any rectification at present, draught cattle being able to make the needful exertion when the strain is not too continuous; metal however should undoubtedly be employed, and the form of the road preserved. Felling of high jungle on either side is also much needed in many places.

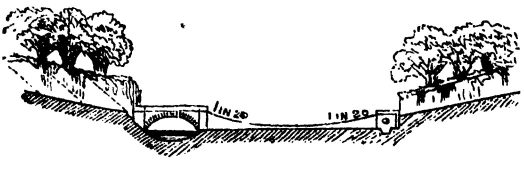
The point however chiefly requiring attention in both roads, is how to deal with the embankments crossing paddy flats; these having suffered most severely from floods, during the last three years—these floods, as I have at the commencement stated, being I believe progressive, in proportion to the extent of land cleared for planting, and liable as has already been the case, to stop all communication, by blowing up the bridges, &c. These flats or cultivated Coorg valleys, present quite a peculiar section, the result no doubt of the incoherent nature of the soil before alluded to. Instead of gently sloping off into the valleys, the hills terminate always in abrupt banks (AB and CD in the above section,) which vary from 20 to 40 and 50 feet high—the stream shown at the left corner, having probably wandered from side to side, (*i. e.*, from B to D,) much in the manner of the Ganges, and other rivers of Upper India, within the limits of their "Khadir." An irrigation channel taken off high up, runs usually along the other side (D), and the stream when surcharged, inundates a large portion, if not the whole intervening space. These paddy flats vary in width from 100 to 500 yards as a rule. Some however in South Coorg much exceed this, presenting magnificent sheets of cultivation girt by densely wooded hills.



In carrying a road across such places, (they are met at distances varying from half to two miles apart,) the plan adopted was to throw an arch over the stream at B, also a tunnel for the irrigation channel at D, the roadway being formed in embankment, somewhat as indicated by the dotted line in the above section. In the middle of this embankment at E, was also constructed a small bridge for the discharge of surplus inundation water.

These arrangements answered sufficiently well, so long as the floods remained within their original bounds—now, however, that the tendency to increase yearly has shown itself in several cases, the irrigation drain at D, and in more cases, the small bridge at E, have blown up. Five embankments crossing paddy flats between Mercara and Veerajendrapett, have thus suffered during the past two years. In the early part of this monsoon, the Kokeloor embankment, close to Veerajendrapett, was for the first time since its construction, (supposed to be 15 years ago,) over-topped, the flood standing 4 feet above the small central bridge, which it fairly blew up, transporting the whole of the materials to a distance of some 50 or 60 feet. The bridge over the stream at B, has always been saved by the destruction of the smaller one at E, the inundation water thus venting itself—but it is perfectly clear that if we go on increasing the embankment to what we consider a safe height, and rebuilding the central bridges at E, considerable risk will be incurred of throwing too great a portion of the flood through B, and destroying thus the main works. Most of the latter are single span bridges of 40 to 55 feet, and were very costly.

In dealing with what, as I judge, has now become a gradually accelerating force, the first necessity is to provide for the safety of the bridges at B. I would therefore instead of raising the embankment and rebuilding the bridge at E, cut down the former and omit the latter, making the whole assume the section shown, which allows the inundation after a few feet rise to flow over the centre of the embankment and thus vent itself innocuously.



There are only two essentials in dealing thus with the matter, viz., first, that the gradient of the approaches shown should be a maximum; and secondly, that the central point of the embankment should be kept as low as possible consistent with this. I have every reason to believe that no flood would thus interrupt the communications more than three days at the farthest, and a few trifling repairs to earthwork would suffice after its retirement.

Having now reviewed the state of the main lines, I will briefly refer to those under construction or proposed.

The road now under construction between Mercara-Somwarpett—and Codlipett—44½ miles—was commenced some three years ago, and during last year had made such advance as to admit of carts going over it. Of course however the work is far from complete. The original idea in thus connecting Munzerabad and Coorg, was to run the line to Sonticoopath, but it was afterwards altered to Mercara, as holding out greater advantages. The line having been laid out, under stringent regulations in regard to gradient, and the trace receiving great attention, the result is a road with uniformly the best gradients in this Province. With one or two very trifling exceptions, I think the maximum gradient throughout the line as far as Somwarpett, may be pronounced to be 1 in 18; 1 in 20 is common on the ghaut portions. In ascending the hill beyond Somwarpett, I fear the gradient is 1 in 16, but after that to Codlipett, 1 in 19 and 20 is the maximum—the line in most places being very easy and often nearly level. Most of the roadway is 18 feet wide. There are places 16, others 14, and even only 12 feet wide: but these form a small proportion, and I should think that in three months the full width will be attained from first to last. The work is progressing with very creditable activity.

For the Choranhully, a single timber trussed span of 50 feet is proposed; for the Mahdapoor two similar spans, and for the Huttyhulla three spans of 50 feet. All of these streams run eastward, forming after their junction the Haringhy river, which joins the Cauvery a little above Ramasammy Cunavi. The Choranhully is narrow, and having a rapid longitudinal fall, comes down with great force when in flood—a causeway is therefore inapplicable, as also the maintenance of communication by means of a ferry. I see therefore no other course than to construct the bridge as proposed. The Mahdapoor has already had a rough stone causeway thrown over it, which has perfectly withstood the last two monsoons. As it answers every purpose of cart traffic for nine months in the year; and as further, the communication during the remaining three, is now maintained by basket boats, (two wretchedly small affairs which should be replaced by a proper ferry boat,) I do not see any very urgent necessity for bridging the stream. The same remarks apply to the Huttyhully, across which the Executive Engineer is about to construct a causeway, similar to that at Mahdapoor.

The next work of communication now under execution by this Department, is the trace of the proposed line from Veerajendrapett, viâ Ammuty and Seedapoor to Fraserpett—in all 28 miles. Of course, like all Coorg roads, the trace is up and down hill, and crosses paddy flats at every one or two miles. I found however the gradients all very fair, the only real difficulty being in, and immediately leading out of, the town of Veerajendrapett itself. Within the limits of the town, the main streets of which have gradients of 1 in 10, it has been found necessary to bring in the new line from the Mercara road, and then take it by a zig-zag up the face of a hill to the east and over a saddle.

In addition to the roads designed, and carried out from Imperial funds, others are now being constructed by planters from their own private means. Though not having personally inspected these, and thus unable to offer any accurate information regarding them, I think it only right to place on record, however imperfectly, the facts connected with this new and encouraging element of advance, and have therefore shown roughly on the map, the direction of two of the most important of the lines in question.

Having now shown generally the condition of the existing work in Coorg and what rectifications are urgently called for, I now turn to a matter of very nearly equal importance, namely the communications needed to keep pace with the rapid spread of European enterprise in nearly every part of the Province.

The Bagamungalum-Sooleah road, has already been sufficiently alluded to. That proposed from Veerajendrapett, viâ Nalknad to Bagamungalum, would if added, open up probably the finest forest land in the country, and with the Sooleah road, supply a through independent Western communication, valuable alike for commercial and administrative purposes.

The next line, namely, that proposed from Veerajendrapett to Wynaad, would I presume lead, as I have roughly shown on the map, through the town of Kuggutnad, and I would recommend that advantage be taken of this new proposed line to Kuggutnad, to open an entirely new road over this portion, tending more to the east where the lie of the ground appears favorable.

From all that I can gather, it would appear that Kuggutnad in addition to this direct connection with Veerajendrapett, would equally need a line leading eastward towards Mysore, joining the Anchowkoor road at some such point as Tittamutty.

The Seedapoor-Fraserpett, and Seedapoor-Periapatam proposed lines, have already been sufficiently adverted to above; it only therefore remains to note that from Fraserpett to Somwarpett, on the Mercara-Codlipett road. The necessity for this road has long been urged, I have therefore roughly shown on the map the direction it would take.

The total length of these several district roads may be assumed roughly at 156 miles. To attempt to open these, as fully bridged cart roads, even without metalling, would certainly not cost less than Rs. 3,500 per mile, or a total of Rs. 5,46,000, an amount that with the more urgent calls for rectifying the defective ghaut roads and other engagements, renders it impracticable to aim at this high standard. The main object, which is to execute these works at once, would moreover be defeated. After giving every consideration to the subject, I venture to believe that the real wants of Coorg, would be met by a system of roads suitable to pack-bullock traffic, but traced with such care and deliberation, that they may be individually worked out to cart roads, the moment funds can be spared. Such roads, three yards wide everywhere, with log bridges, maximum gradients on all straight portions of 1 in 19, and at all bends, of 1 in 22, and having causeways over the largest streams, could, I am satisfied be opened for Rs. 600 per mile, allowing the whole network to be executed for Rs. 93,000—or, if the work is to be done in four years—requiring an assignment of say Rs. 25,000 per annum, in each successive Budget.

Very little more than the actual tracing need in practice fall on this Department, as I have no doubt the planters would find it for their own interest, to take certain lengths of line in their neighbourhood upon contract, and work them out by estate coolies. Nay more, I should think, they would be perfectly willing to do the work at once, if guaranteed repayment by Government within the specified four years. However, this is a question they can better answer for themselves. It is clear that for them to do the work, would disturb the labor market less than if *we* did it, and being all of a simple nature and precisely similar to work done every day on the estate, I think it would be found to answer. The Executive Engineer should of course alone lay down the trace and specification for the work, naming the terms, and exacting the strictest adherence to all, on penalty of non-payment. The interests of all parties it seems to me, would thus be met.

As showing the importance of such a system of roads, I would beg to make a brief quotation, from an able and suggestive article on "the Southern Ghauts," in No. LXXVI. of the Calcutta Review, for 1863. The reviewer observes: "We have stated above that in 1853, the Madras Commission on Public Works found that the roads of Canara were returning to Government a nett profit of 20 per cent. from the two sources of land and salt revenue; we shall now take the ten years from 1851 to 1860, and show what has been the progress from about the last year, on which the Commission forwarded its report, to the last at our command. Omitting all fractions below a quarter of a lakh, we find that the import trade rose within the above period from 4½ lakhs to 25½ lakhs; the value of exports rose from 30½ to 102¼ lakhs; thus the whole trade increased from 34¾ lakhs to 127¾ lakhs. In the same period, the salt revenue rose from £14,000 to £31,000; that is to say, was more than doubled"—and more in the same strain. Since this remarkable statement was made, the spring which has been given to enterprise in Coorg, has mainly taken place, and if we could only analyse the returns, the direct gain by Madras would, I am satisfied, be shown to be equal to the whole demand I have ventured to claim for the Public Works in Coorg.

Before closing this Report it is necessary I should remark that in the matter of labor there are great difficulties in this province. During the monsoon, when the ghaut roads require close daily attention, hardly a man is to be had. Mysore coolies who all belong to the agricultural class, have by that time mostly vanished, or find easier and more congenial work on the coffee estates, where each man in addition to his 4 annas per diem, can turn a few annas by the sale of firewood, &c. Mapillay coolies, who require Rs. 10 per mensem, will only work in the low country at the foot of the ghauts. Madras men will again only work on the Periambady-Anchowkoor road, salt fish being easily procured there, &c.

The extreme unhealthiness of portions of the ghauts also frightens labor away from our works. Not a single cooly can at times be induced to go down the Sumpagee ghaut in the monsoon. Many years ago

Captain (Major-General) Frederick Cotton, proposed to establish single cooly huts at every mile, but this as well as other similar attempts in the same direction, have failed signally. Mr. Stoddard has however now, with the sanction of the Chief Engineer, commenced the construction of permanent cooly lines at convenient distances and in comparatively healthy localities. Nine of these now in hand are shown on the map. A small hut attached answers for the road overseer. This system certainly holds out fair hopes of success, but still labor must remain precarious and expensive, coming as it does from a distance.

P.S.—Since writing the above, I have incidentally learned that the same hurrying down of floods adverted to above, accompanied by breached roads and blown up bridges, followed the first clearings in Ceylon, but that some kind of equilibruim has been of late years established by a sensible falling off of the yearly quantity of rain—to the extent of one-third the previous amount. My informant, however, could neither afford me accurate information nor refer me to any printed record. Should this enquiry prove to be well founded, a serious question will follow as to the effects of clearings on the summer water of the Cauvery and the irrigation dependent thereon.

R. H. S.

BANGALORE,
11*th November*, 1865.

No. CXIII.

ON THE THEORY OF ARCHES.

By Alexander H. Macnair, Esq., *Resident Engineer, E. I. Railway.*

This paper is an attempt to construct a theory which shall be of practical value, and to demonstrate the same without the aid of the higher mathematics. In order to present it in a form sufficiently complete to be intelligible, within the limited space which can be afforded, much of the reasoning is merely indicated, and no effort has been made to distinguish what is novel from that which is only a reproduction of the works of others.

Motion as opposed to Stability.—The failure of an arch or other building implies motion among its parts, for it cannot be said to have failed till this has occurred.

A stone resting on the plane AB, Fig. 1, and still remaining in contact with it, may be moved in either of the following ways:—1st, It may slide towards A or B. This is called motion of translation. Or 2nd, It may turn on the edge A or B. This is called motion of rotation. Or 3rd, It may by increased pressure approach nearer to AB, or *vice versâ.** If the pressure is insufficient to crush the stone, it will tend to produce rest or stability, but otherwise motion or failure. And no other kind of motion can take place in the stone still remaining in contact with AB, which is not a combination of some or all of the above.

Now, if the pressure be unequal, the stone may be crushed at one end of AB and not at the other, causing a motion of rotation; the centre of which is a point between A and B. And this is the only case which occurs in practice in an arch. Therefore the stability of arches is endangered *only by unequal pressure.*

[Throughout this paper the points of support of the arch are regarded as immoveable.]

THE LINE OF PRESSURE.—Let Fig. 1, be the vertical section of a stone of equal thickness, passing through G its centre of gravity, and intersecting its horizontal plane of support in the line AB. It is evident that the line of direction (of gravity) GC bisects AB, that the pressure on AB is equal everywhere, and that the total pressures on each side of GC are equal to each other.

In Fig. 2, let the *shape* of the stone be altered, its weight and other conditions remaining the same as before. Then the total pressures on each side of GC, are still the same, but the pressure is greater at A than at C, and at C than at B, because C is nearer to A than to B.

If now, as in Fig. 3, we make CD = CA, and cut off that portion of the stone supported between D and B, and support it on the stone itself, so that the centre of gravity remains on the same vertical line, the area of support is thereby diminished, at the same time that the pressure at A is reduced, because the pressure on AD is now made equal everywhere.

In Fig. 4, let GC be the line of direction (of gravity) of an arch stone supported on AB. The pressure is greatest at A.

In these examples GC is the Line of Pressure.

But the arch-stone may be acted upon by another force besides its weight, as for instance, an external force in the direction DE, *Fig. V.* Then the centre of pressure is at E, where this intersects the direction of gravity. And the Line of Pressure is in the direction of the resultant of of the two forces, intersecting AB in some point F; and the pressure is greatest at A or B, according to their proximity to F, and equal everywhere only if F bisect AB.

To put these results into the form of a definition. In the vertical section of an arch, at right angles to its axis, there is a line of contact between every two adjacent voussoirs, and a point in that line which divides equally the total pressure exerted by these voussoirs against each other. The line which passes through all these points is the LINE OF PRESSURE.

[I have pursued this investigation on the hypothesis that the material *is compressed*, and that the resistance developed, (which is the pressure,) is

correctly measured by the amount of compression. The following is the result in algebraic symbols—

$a = $ AF. $b = $ FB. $p = $ pressure at F (mean) $x = $ ditto A (greatest) $y = $ ditto B (least)	$x = p\dfrac{b^2 + 2\,ab - a^2}{b^2 + a^2}$ $y = p\dfrac{a^2 + 2\,ab - a^2}{a^2 + b^2}$	Let $y = 0$ then $x = p\sqrt{2}$ and $b = a\,(2{\cdot}4142)$

so that if AF is not more than two-fifths of FB, there will be no pressure, but an open joint, at B.]

Before proceeding to the next head, it is necessary to define the sense in which certain terms are used in this paper.

Moving Load requires no explanation.

Permanent Load is that which is necessary to render the arch useful. At the crown of the arch there are always the *arch-stone* and the *permanent load* on it, and occasionally the *moving load* also. The permanent load is uniformly distributed over the span of the arch.

Backing is that which remains on the arch-ring when the moving and permanent loads are both taken away. It is more or less essential to the stability of the arch, and in reference to its weight, must always be taken into consideration along with the arch-ring.

Arch-ring requires no explanation.

Structure includes all of the above except the first.

Causes which determine the Line of Pressure.—1st. *Weight of Structure.*—In illustration of this I shall consider one case, viz., that in which the structure is designed so that the Line Pressure shall bisect all the lines of contact. And for the present let the Permanent load = 0.

In Fig. 6, let HI, IK, be straight lines joining the centres of gravity of three arch stones, of such dimensions that the horizontal distance of I from H is equal to that of K from I. It is required to determine the conditions of stability of the middle stone, so that the Line of Pressure may pass through the points H, I, and K.

The diagram itself will show how this is accomplished. The point I is kept at rest by the equal and opposite horizontal forces, LI and NI, and the vertical forces PM + MI, which are together equal to the opposite force OI. Now MI is the whole weight supported at H; and because this is not sufficient at I we have to add PM, which must therefore be the weight of the arch stone at I, and the backing directly above it. It remains to calculate PM.

In Fig. 7, we pass on to the consideration of blocks of masonry having their centres of gravity in vertical lines which are at equal distances from each other. These blocks make up the structure, which in this case consists of the arch and backing alone. And by comparing Figs. 6 and 7, it is evident that to calculate PM for any one of the vertical lines, we must find the length of the portion cut off from that line, and deduct from it the length of the portion cut off from the line before it (towards the centre). The remainder is PM. This can be done in various ways.

Tables are given below for Radius divided into 10 equal parts. Their application will be readily understood, bearing in mind that PM, at the crown is *half* the weight of the vertical block, and in every other position it is the *whole* weight. The first three Tables are general. No. IV. requires to be made out for each arch, after the Radius of the Line of Pressure and depth of the key-stone are known. It is subdivided to show the difference in backing between two arches otherwise alike, caused by a difference in the depth of the arch stones, which is worthy of notice. Fig. 8, shows two semi-arches drawn according to this Table.

RADIUS DIVIDED INTO 10 EQUAL PARTS.

No. of division from centre.	RADIUS = UNITY.			RADIUS = 10 FEET.	
	Table I.	Table II.	Table III.	Table IV.	
	Versed sines.	Differences of versed sines or lengths cut off in Fig. 7.	Differences of last Table, or value of P M.	Height of block, when key-stone = 1 foot.	Height of block when key-stone = 2 feet.
0	·0000	·0050	·0050	1·00	2·00
1	·0050	·0152	·0102	1·02	2 04
2	·0202	·0259	·0107	1·07	2·14
3	·0461	·0374	·0115	1·15	2·30
4	·0835	·0505	·0131	1·31	2·62
5	·1340	·0660	·0155	1·55	3·10
6	·2000	·0859	·0199	1·99	3·98
7	·2859	·1141	·0282	2·82	5·64
8	·4000	·1641	·0500	5·00	10·00
9	·5641	·4359	·2718	27·18	54·36
10	1·0000				

Fig. 8.

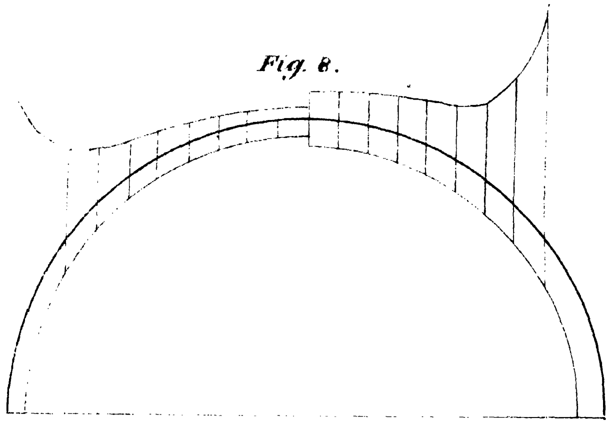


Fig. 9.

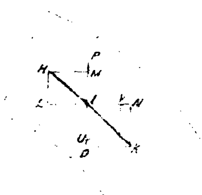


Fig. 11.

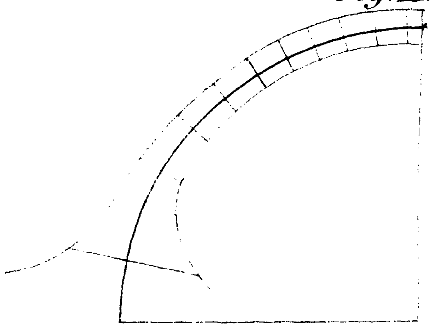
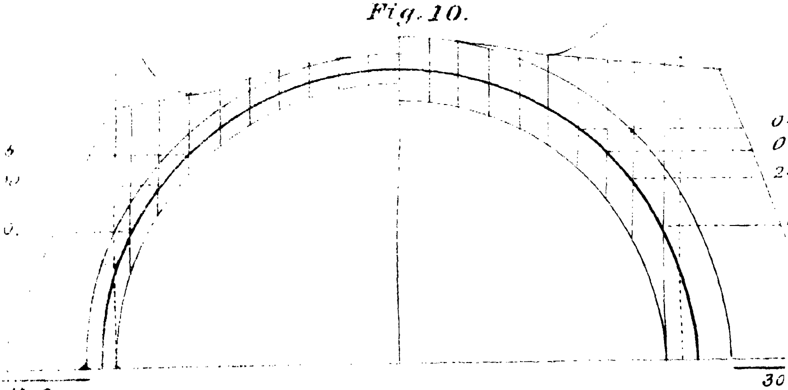


Fig. 10.



This reasoning is believed to be correct for that portion of the arch which is near the crown; for there are no forces acting on it, except its own weight, and the resistances by which it is supported. But as we approach the abutment, another force comes into operation which increases the stability of the arch without adding to its weight. In Fig. 9, let PM be determined by convenience instead of calculation, and be less than OI — MI. Then making IU = IP, there remains a horizontal thrust VN to be balanced. This will be accomplished if we have on the abutment at or above that height, a weight of masonry sufficient to resist the horizontal thrust VN by its friction, the abutment itself being immoveable. Fig. 10, shows the same two semi-arches designed according to these principles. The two vertical dotted lines show the theoretical division between the *backing* which acts directly by its weight, and the *masonry* which acts by its friction. The horizontal dotted lines indicate the points in the Line of Pressure which receive support from this last, and the figures outside give the sectional area which I have calculated is required at each point. The whole horizontal thrust of the arch must of course be balanced by the whole friction developed. It is only further necessary to provide against the backing being overturned, which I have here done by extending its base. This is not advanced as a desirable model to copy in actual construction. It is the development of the theoretical principles on which we should design an arch, to stand even when built of very soft materials, because they would be used to the best possible advantage.

We have hitherto considered *Permanent load* = 0. But to make the arch of use there must be some permanent load. It will form a portion of PM at each point, but the relative values of the different PM will remain as before. Indeed there is no reason why the moving load also should not be included in PM, as we shall see further on.

2nd. *Elasticity of the Materials of Construction.*—The most general notion of elasticity is an effort on the part of the elastic substance to assume its normal shape. Those dimensions which have been extended tend to reduction, and those which have been compressed, to increase. As we assume no adhesion in the materials of the arch, the elasticity in this case includes *compressibility* alone. If the compressibility were great, it would materially affect the Line of Pressure, by *shortening* the arch after it was built. But it is so small that we may neglect its operation in this respect. It affects the Line however through the masonry which acts by its friction. For this masonry exerts no pressure *on* the arch till it is first pressed *by* the arch, which the compressibility of the material does not permit without an *increase* in the length of the radial line, accompanied by a *decrease* at some other point, probably at the crown. Hence the form of the arch undergoes alteration after it is built, in consequence of compressibility. It is enough to direct attention to this fact without attempting to push the investigation further. We cannot prevent the operation of the cause, but we may do something to neutralize its effect in practical construction.

3rd. *Moving Loads.*—We have seen that we may construct an arch so that the Line of Pressure shall bisect the lines of contact under one set of conditions. The converse of this is a problem much more difficult to solve, viz., to determine the position it will assume under different conditions.

If we fall back on the principle of applying more weight to counteract the horizontal thrust as the resultant becomes more nearly vertical, we shall find that the weight required at the springing of a semi-circular arch is nothing less than infinite. Hence we might be justified in concluding that the Line of Pressure will bisect the line of contact at the springing or a little below it, and that this result would not be affected by any change in the moving load which is finite. There is no doubt that this conclusion is theoretically perfectly correct, and there seems to be no reason why the Line of Pressure should not follow exactly the same curve, when we balance by other means the horizontal force for which this infinite weight was required. The subject is difficult to reason upon and not directly profitable, for there is no practical question as to the stability of the lower part of a semicircular arch. And we shall fall into no practical error if we assume that the horizontal distance between the extremities of the Line of Pressure does not vary, whatever may be the variation in the load, and adopt this principle as the ground work of our reasoning in arches of every variety of form—segmental, elliptic, or otherwise.

If a given load be placed in any position on an arch of which this principle is true, we know at once how much of its weight is supported at each end of the Line of Pressure, because we know its horizontal distance from each end. And we shall determine the amount of horizontal thrust due to the load, if we can ascertain the vertical position of its point of support. Now, this is approximately the same as that of the block of masonry on which it rests. If we assume them to be identically the same, we may combine the pressures of the structure, and the moving load, both vertical and horizontal, and so construct a curve which will vary but very slightly from the actual curve of the Line of Pressure. (Figs. 11, 12, 13.) But after having determined the *shape* of the curve, and knowing the *horizontal* position of its extremities, we have yet to fix its position vertically, which we may do, approximately, by taking into consideration the elasticity of the materials. For we know that the pressure on the outside of the arching will be greatest at a, and on the inside at b, and that the Line of Pressure will adopt such a position as to equalize these greatest pressures. And without entering into calculations it is sufficient to suppose that this is accomplished when the curve at a and b is equally distant from the line which passes through the middle of the arch ring; by which the vertical position becomes definitely fixed.

We can thus determine the Line of Pressure when a given load is placed on an arch, in which the Line of Pressure would pass through the middle of the arch-ring when there was no load on the structure. Conversely we may design the arch to satisfy this condition when a certain Moving load *is on* the structure, and then determine the position of the Line when any portion of this load is taken away. This is the method here adopted, for the following reason:—

Let n = greatest Moving Load which can possibly be placed on one division of the arch, of which there are 20. Then the whole load may possibly be $20n$, but not more. And as this will cause the most severe test which can be applied, we ought to design the arch so that the Line of Pressure shall pass through the middle of the arch-ring when the load is $20n$.

Figs. 11, 12, 13, show the position of the Line of Pressure, calculated according to these principles under several different conditions.

In Fig. 11, the semicircle shows the Line of Pressure under the maximum load ($20n$), and the other curve shows it when all the load is removed.

In Fig. 12, the sharper curve shows it under a load of $7n$ applied at the crown, the remaining load of $13n$ being removed from the haunches ($6\frac{1}{2}n$ from each side). The disturbance of the Line under this load is a *maximum*, that is to say, it would approach more nearly to a semicircle, if the load were either increased or diminished. The flatter curve shows the Line of Pressure under a load of $9n$ applied at the haunches ($4\frac{1}{2}n$ on each side), the remaining load of $11n$ being removed from the crown. The disturbance in this case also is a *maximum*.

Fig. 13 shows the Line of Pressure when the load is removed from one side altogether, and also from the central division, being the nearest approach to an arch loaded on one side only, which the present method of investigation admits.

These curves are calculated on the hypothesis that the load n is equal to 4 times the weight of the block of masonry whose centre of gravity lies in the vertical radius, which is of course greatly exaggerated. I have done so to show a sensible difference between the different curves, on the small scale on which they must be printed. With the exception of the semicircle they are, as explained, only approximations, but probably close approximations, to the true curve of the Line of Pressure under the conditions indicated.

The effect of *velocity* in increasing the pressure of a Moving load is a consideration closely connected with this subject, regarding which however there is but little known even in the case of iron girders, and still less in any other.

Depth of Arch-ring.—An arch-stone may be considered in two ways, viz:—1st, As a portion of the arch necessary to its stability; and 2nd, As a portion of the arch which enables it to carry loads.

1st.—In Figs. 6 and 7, I have illustrated the conditions of stability of an arch constructed to stand by itself, without reference to its capability of sustaining any load. The weights of different portions and the pressures exerted by them are there measured by constant quantities, which must bear the same proportion to each other in every case. If, therefore, the material which we select to build the arch be sufficiently strong, the quantity in which we use it is a point of no importance. If the arch can be built of brick, it is just as strong if it be only one brick thick as if it were ten. For every square inch of sectional area to support weight, we have exactly the same number of cubic inches of material to be supported. We may increase or diminish the quantity as we choose, but we can neither increase nor diminish the pressure per square inch.

2nd.—Let us now consider the arch stone as a portion of the arch which enables it to carry loads. If the material be, however little, stronger than is necessary to support the arch, its remaining strength is available to carry loads. Here the depth of arching becomes important, for the excess

THEORY OF ARCHES.

Fig. 11.

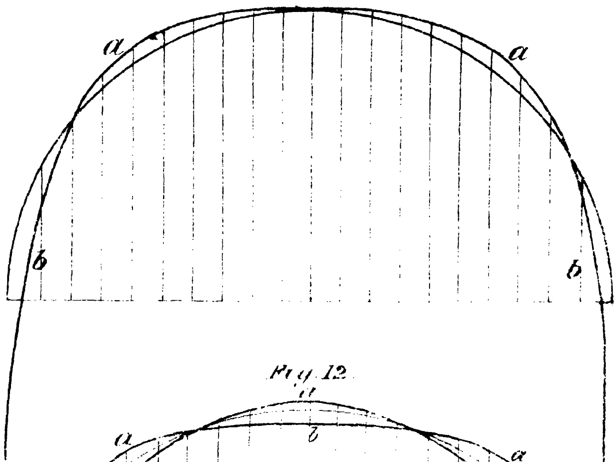


Fig. 12.

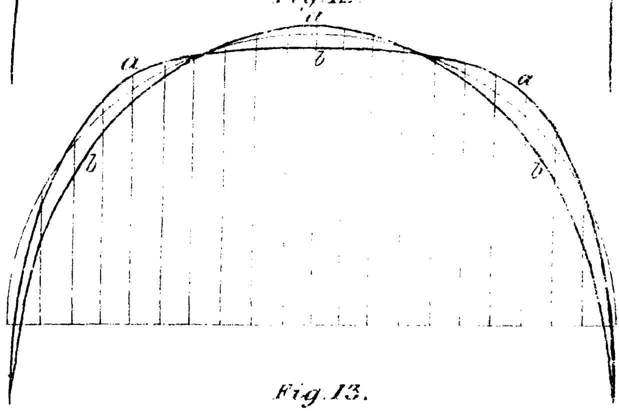
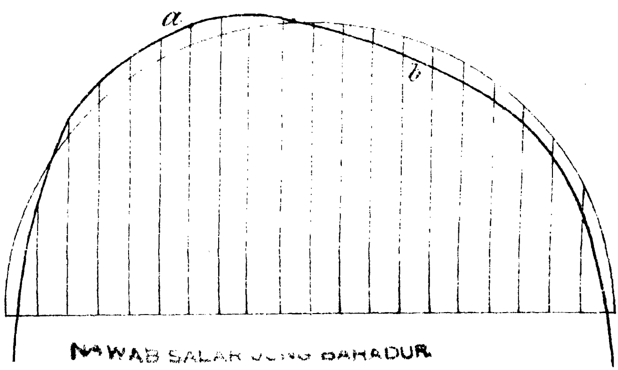


Fig. 13.



of strength in one square inch of bearing surface becomes multiplied by the number of square inches, and the load which the arch may sustain is therefore in proportion to its depth. Moreover, if the load be not all permanent, there must be a certain depth in the arch-ring on account of the disturbance in the Line of Pressure caused by an alteration in the moving load. Therefore an arch-ring which has to sustain any load, requires a certain amount of depth to give it *strength.* And if any portion of the load be variable, it requires a certain amount of depth to give it *stability.*

Although it is necessary to consider the arch stone in these two ways separately, in order to arrive at a correct notion of the duties which it has to perform, we do not require to keep up the distinction any longer. Having assumed the greatest possible moving load, we may combine that with the weight of the structure. Then the arch-ring is of sufficient depth when the two following conditions are fulfilled:—1st, The extreme pressure must not be greater than the material can resist; 2nd, The depth of arch-ring must be sufficient to permit the greatest possible disturbance of the Line of Pressure without bringing it dangerously near to either extremity of any one of the lines of contact.

This phrase "dangerously near" has a precise meaning. When the whole arch is uniformly loaded with its greatest possible moving load of $20n$, the pressure in each line of contact is equal everywhere. When any portion of this load is taken away, the total pressure on each line of contact is diminished, but the Line of Pressure having been disturbed, it is greater at one end than at the other. And if the pressure at either end exceed the original pressure under the load of $20n$, then the Line of Pressure has approached "dangerously near" to that extremity.

The next step towards the depth of arch-ring is to ascertain the rule according to which it ought to vary in arches of different proportions. The object in view is of course to secure an equal degree of stability in each. Now the stability of the arch is affected by the four following magnitudes:—1st, The radius of the Line of Pressure, or (in less accurate terms) of the arch at the crown; 2nd, The depth of arch at the crown; 3rd, The weight of the structure; and 4th, The weight of the moving load. Moreover, it is evident that if we increase the weight of the moving load, or decrease the depth of the arch, we must increase the weight of the structure, or decrease the length of the radius, to obtain the same degree of stability in the arch. This condition does not imply a proportion between the four terms, yet we see that if we make them proportional it will be satisfied to some extent. For, if we make the radius to the depth, as the weight of the structure is to the weight of the moving load, then we cannot increase the load or decrease the depth without either increasing the weight of the structure or decreasing the length of the radius. But it is more in accordance with the principles already laid down to compare the weight of the moving load with that of the structure and moving load combined, which we may call the *whole weight.* Now let R = radius, D = depth, L = load, W = whole weight; and let l = load, and w = whole weight, of an arch whose radius and depth are each = unity. Then the proportion is R : D :: W : L, or $\frac{D}{R} = \frac{L}{W}$. Now, the load being the same per foot run for every arch, may be expressed in general terms $L = Rl$, and the whole weight depending on the length of radius and depth of arch-ring, $W = RDw$, whence the general equation becomes

$$\frac{D}{R} = \frac{Rl}{RDw}; \; D^2 = R\frac{l}{w}; \; D = \sqrt{R}\sqrt{\frac{l}{w}}$$

so that the depth of arch should vary as the square root of the radius $\sqrt{\frac{l}{w}}$ being a constant quantity.

I have not been able to assign a value to this constant. The value given in practical treatises is 0·12 for single arches, and 0·17 for arches in series. There is no doubt that these values have been arrived at by careful comparison of good examples; whether the result can be verified by theoretical reasoning is a point I am at present unable to determine. The proportion which should exist between l and w is probably involved in the conditions required to prevent the Line of Pressure from approaching dangerously near to either extremity of the line of contact (see above).

If it be desired to increase the depth of arching from the crown towards the haunches, as is frequently done in segmental arches of large span, the principles of this theory can readily be applied to lay down the rule according to which the increase should be made. In Fig. 6, the total pressure on I from above is HI, and on K is IK. Therefore, the strength of the arch between I and K should be greater than that between H and I in the proportion IK to HI. In Fig. 7, we may at once proceed to the limit, and make the lengths of the arcs cut off be the measure of the depth at the middle of each arc. These arcs give nine dimensions, and we can also find two more, viz., one at the crown where the pressure is only horizontal, and its measure is one division (one-tenth) of the radius, and the other at the springing, which is infinite.

This principle may be applied with advantage in very large segmental arches, in which the rise is not more than one-fourth of the span, *see* Fig. 14, which is drawn according to the following Table, giving the calculated depth for the nine intermediate points when the depth at crown is 1.

Horizontal distance.	Depth.	Horizontal distance.	Depth.
Crown.	1·000	0·6	1·198
0·1	1·001	0·7	1·318
0·2	1·012	0·8	1·522
0·3	1·033	0 9	1·928
0·4	1·070		4·509
0·5	1·120	Springing	infinite.

Points of Rupture.—If the theory now submitted be correct, we shall be able to get rid of these points altogether. An arch designed according to this theory, if it be loaded with its greatest possible load of $20n$, has then no points of rupture. It may fail if the material be simply crushed, but not otherwise; for the Line of Pressure bisects all the lines of contact, and the pressure in each of these is therefore equal everywhere.

Such is the condition of the arch under the *greatest* possible moving load. Therefore, we cannot possibly disturb the Line of Pressure, except by *taking away* some of the load. Suppose we take away all the load from one side of the arch and none from the other; then we have disturbed the Line of Pressure probably to the greatest extent possible. But we have also reduced the moving load by one half. We must now ascertain whether there is any portion of the arch-ring under these altered circumstances which bears a greater pressure that it did at first. If there *is not*, then there is no point of rupture. If there *is*, we may still hope to remedy the defect by an alteration in the proportions of the structure and its load.

To ascertain whether any point of rupture does exist, is simply a matter of calculation, which the theory shows us how to perform approximately. Nor is this all, for the approximation may be used as a fresh point from which to start new calculations, the results of which will be still more near the truth. And I have no doubt that by successive approximations we might attain to any required degree of accuracy. Thus it may perhaps be possible to lay down a certain proportion between l and w (*see* above) which will exclude the possibility of a point of rupture in any arch designed according to the formula $D = \sqrt{R} \sqrt{\frac{l}{w}}$.

SUMMARY.—The propositions advanced in this paper are briefly these:—

1st.—That it is in our power to cause the Line of Pressure to bisect all the lines of contact between voussoirs, under one set of conditions.

2nd.—That we should construct the arch so that these conditions shall be satisfied when the greatest possible load is placed on every portion of the arch.

3rd.—That the depth of arch-ring of an arch which does not carry weight is independent of its span or radius.

4th.—That the depth of arch which is required in proportion to its radius, depends on the proportion which exists between the weight of the structure and of the moving load, and also in some respects on the velocity with which the load moves; and that the conditions of this latter relation are but little known.

5th.—That arches may be designed in which there shall be no points of rupture, properly so called.

A. H. M.

25th June, 1866.

No. CXIV.

RIVER WORKS ON THE GOGRA.

Memorandum on the means employed for the demolition of Sunken Trees and Kunkur Rocks on the River Gogra in Oudh. BY LIEUT. W. J. CARROLL, R.E.

THE banks of the Gogra for a large proportion of its course, from the north of Oudh to its junction with the Ganges above Dinapoor, consist of alluvial soil, deposited by the river itself in its higher floods, and liable to be demolished as rapidly as they are formed; in their destruction, villages and trees are carried away, and the latter, when of any size, generally remain fixed in the bed, and become dangerous obstacles to navigation, more especially in the rains.

In addition to this danger, common to all rivers with alluvial banks and subject to severe floods, there are a large number of sunken kunkur rocks and ledges projecting from the main bank where it is formed of that material. Many of these rocks are detached, but the majority of them are connected with the bank by beds of kunkur at greater or less depths under the surface. They are in fact but the more elevated portions of such beds, and the complete demolition of a rock, would, in the majority of cases, involve the removal, not only of such portions as appeared near or above the surface, but also that of large contiguous beds in depths of several feet of water, which is, a much more extensive operation than that generally implied by the "removal of a sunken rock."

During the last two cold seasons, works have been in progress for the removal of these dangers. In the case of trees sunk in the channel, no difficulty has been found that cannot be easily surmounted; but the method that has been used for the removal of those buried in sand below water-mark is still open to improvement. For the removal of kunkur rocks, no large operations have been yet undertaken, and the mode which has been employed in the little that has been done, may, perhaps, also be improved upon. Operations were commenced last year under unfavorable circumstances, and without the time for procuring proper appliances; the means first employed will therefore be quoted rather as examples of what to avoid than of what to imitate; in this way they may be of some service.

It is necessary, in the first place, to describe the general features which produce the difficulty of removing a sunken tree. The current of the Gogra flows in many places 2½ miles an hour, or 3·6 feet a second. This speed is quite common round the edges of a kunkur rock, or between the branches of a sunken tree; in many such places it is much higher than this, and as the pressure of the current is proportional to the square of the velocity, the difficulty of working boats, or placing charges of gunpowder may be considered to increase in the same ratio. The trees are found sometimes wholly, sometimes partially, immersed in the channel, or they are found partly or wholly buried in the sands, and only creating danger in the rains, when the floods rise over their branches and hide them; or they are found thrown up on the sands and not imbedded, or lying fallen on the banks ready to be swept in at the next floods; but wherever they are found, they offer a very indifferent mark for the action of gunpowder. The roundness of the branches and their small surface compared with their strength, the toughness of the roots, and the massiveness of the stem, combine to make the removal of a large tree a tedious and difficult matter. It presents no large and weak surface like the hull of a sunken ship, and it lies usually in shallower water which offers less resistance as tamping to the charge. When broken up, the pieces, often of great weight, have to be dragged in and lifted up upon the high main bank, to prevent their being again carried into the river during floods, and becoming fresh obstacles. The above description applies to the largest class of trees, of which many have been found with stems 10 feet and more in diameter. The removal of a small tree is of course proportionally easier.

The means employed for the blasting of trees last year, in the absence of better ones, were charges of from 25 to 50 lbs. of gunpowder, contained in tin cylinders, and fired by means of tin tubes rammed with fuze composition, and attached to the cylinders by a water-proof joint. The cylinders were provided with loops of iron-wire projecting from the side, by means of which they could be lowered into the selected spot, by sliding them down bamboos, previously driven in and stayed against the branches of the tree. This method of placing the charge has been retained, as it is found that no moderate weight attached to the cylinders will retain them in their places in a strong current, and because in many places a diver cannot be safely sent down to place the charges.

The mode of firing by fuze tubes was abandoned as soon as possible; it was very inconvenient at any time, and the tubes were liable to break; they were also very uncertain in depths even of 6 feet, and they could not be employed at all in considerable depths.

Bickford's fuze was not procurable at the time, and Brunton's water-proof fuze, though obtained, was not of the quality fitted for burning to any depth under water with certainty. Bickford's fuze has since been obtained from the arsenal at Allahabad, but has also proved uncertain in depths of from 10 to 15 feet. However, I am not aware whether it is of the same quality as that employed in submarine works in England, and denominated Sump fuze; and it is moreover, possible, that the working of the fuze, and the friction against the branches of the tree caused by the strong current in which it was here used, may have rendered it less water-tight than it would be in still water.

A third method of firing charges employed last year, and in the present, has been found very effective and,—granted that the cylinder and tube have been properly tested,—it is perhaps the most certain of all. Instead of the thin tin tubes above described, a tube of about three-fourth inch diameter is employed, and soldered into the cylinder near one edge. A thin bamboo lashed to the cylinder and tube secures the latter from being injured, and the cylinder and tube thus prepared and tested can be stored in the magazines ready for use. The testing is done simply by filling the cylinder with water, through the tube, till the latter is full to the top. If the cylinder will stand the pressure of a 10 feet head of water thus applied without leakage, it will bear to be immersed (when filled with the charge) to a depth of 15 feet, or if very tightly filled, to a depth of 20 feet. The charges thus prepared may be placed, as before described, by sliding them down on bamboos into the chosen spot. The firing is effected in the following way, which I believe to be novel. Into the top of the tube, which projects above water, is fixed a fuze which is rammed in a tin tube 9 inches long and of a slightly conical shape. The composition of the fuze contains near its head a pellet of iron of about half the diameter of the lower end of the tube. The burning of the fuze makes the pellet red-hot; it is prevented from blowing out upwards by two cross wires, and consequently when the fuze has burnt out, the pellet drops through the tube, and ignites the gunpowder. A large number of charges have been fired in this way, and no failure has ever occurred through the pellet's not falling or not being hot enough. Charges thus prepared have been used in from 15 to 20 feet of water, and it is manifest that with flexible tubing, such as block tin gas-pipe, that they might be employed in much greater depths and with some advantage where time did not admit of the construction of a galvanic battery. The fuzes should be rammed with ordinary fuze composition, which is a mixture of—

	lb.	oz.
Saltpetre,	3	4
Sulphur,	1	0
Mealed powder,	2	12

and care should be taken that the pellet is always considerably smaller than the tube it has to fall through, and that it is not angular in shape.

But though the above may be a better method than employing quick-match or filling the tube with composition, where, for want of better means, it has to be employed, it possesses all the objections common to the tube system, and is altogether a less workman-like way of proceeding than the use of the Galvanic or Magnetic Battery. The former has not been employed on this river; for though one was constructed, the materials at hand were not sufficient to make it of the required power, and it was put aside for future completion. Full information on the subject is given in Volumes IV., VI., and VII. of the "Professional Papers of the Royal Engineers," new series, and in Mr. Tresham's pamphlet on its employment on the Ganges River works.

The Magnetic Battery has been employed this year with success, and though the mode of using it and the construction of the fuzes are amply detailed in Messrs. Wheatstone and Abel's Report on the subject in Volume X. of the Professional Papers, Royal Engineers, part may be repeated here in order to render the account of the rough but effective fuze here employed more distinct.

The ordinary fuze consists of a wooden plug carrying a gutta-percha core inserted through its axis, and containing two fine copper wires insulated from each other. The core projects three-fourths of an inch from the lower extremity of the plug, and its end is cut off clearly, so as to expose the extremities of the wire, which are one-sixteenth of an inch apart. The upper ends of these insulated wires are separated from each other, and put into connection with two small copper tubes or eyes, which are fixed cross-ways in the head of the plug. These eyes are intended for the reception of the main wires of the battery, and the current in passing has to flow by the insulated wires contained in the core of the fuze, and to leap the interval of one-sixteenth of an inch which separates them. To enable it to do this, the exposed ends of the wires are covered with an explosive composition of feeble conducting power, consisting of an intimate mixture of the following ingredients:—

Sub-phosphide of copper,	10	parts
Sub-sulphide „	45	„
Chlorate of potassa,	15	„

About a grain of this composition is inserted into a small cap of metal foil which is twisted on the end of the gutta-percha's core ; and the bursting charge is contained in a tin tube of a few inches in length, which is fitted on to the end of the fuze plug, and corked at its lower extremity.

When the fuze is about to be used, and has been prepared in the manner described, the end of the wire which leads from the battery is pressed into one of the copper eyes, and another shorter wire is pressed into the other eye, and its upper extremity put into connection with the outer surface of the vessel containing the charge, if it be of metal or with a metal plate attached to it; if it be of wood, the circuit through the fuze and main wire is completed by the water between the surface of the cylinder (or the metal plate), and a metal plate attached by a short wire to one of the poles of the battery, and immersed in the water. The neck of the cylinder through which the fuze has been inserted is of course stopped with a water-tight plug. The charge being thus prepared and placed, the boat containing the magnetic battery is withdrawn to a convenient distance, and the charge is fired by a smart turn of the handle of the battery, which, by causing the armatures of the magnets to rotate before their poles, produces the succession of induction current necessary for ignition. The main wire leading from the battery must be carefully insulated from the water, and the connection of the return wires with the water carefully made. The other connections with fuze and battery need not be made with as much care as when working with the galvanic battery; for, here we have to deal with electricity of higher tension than is produced by any galvanic battery of moderate power.

This description of the fuze and its use, all of which may be found in greater detail in Messrs. Wheatstone and Abel's Report, above referred to, will enable me to dispose of the rough, but effective fuze, here employed in a few words. In place of the wooden plug, a cork is employed, which does the double duty of holding the gutta-percha core and of corking the cylinder. The core itself, instead of the carefully manufactured article above described, may be simply made by taking two pieces, each a few inches long, of single insulated copper wire cut from the coil employed as main wire, cleaning them for about half their length, and fuzing them together by passing a hot iron over the gutta-percha with which they are covered. They are then pressed together till the ends of the wires are one-sixteenth of an inch apart. A shorter interval may be employed with advantage, say one-twenty-fifth of an inch. This core is passed through the cork, and the portion of the fuze wires which have been cleaned and exposed, project above it for the purpose of making connections. One of these, supposing the fuze to be primed and placed in the cylinder, is bent over and put into connection with the metal of the cylinder, generally by folding it up with a little slip of tin projecting from the neck; the other is put in connection with the main wire of the battery.

The priming of the fuze is previously effected by cleaning the inner end of the core, wrapping a small paper cartridge round it, inserting a grain of the magnet fuze composition, and filling the rest of the cartridge with mealed powder slightly rammed, to prevent it and the fuze composition from separating from the end of the wires. The end of the cartridge may be plugged with wax. This small cartridge is quite sufficient as a bursting charge for 50 ℔. charges; but for larger charges, a larger one would be preferable, and could be tied round the cork, which would then be passed altogether into the charge, and other arrangements made for corking the cylinder.

A water-proof substance must always be employed to cover the top of the cork, and protect the connection of the main wire with the fuze which is just outside it, from the water. The substance here employed is that called Kitt composition; it consists of a mixture of the following ingredients, slowly heated together:—

	lbs.	oz.
Resin, ...	7	8
Pitch, ...	6	14
Bees' wax, ...	6	14
Tallow, ...	1	14

In warm weather it should be kept cool in water, or it becomes too soft to use with convenience; in other respects it is perhaps the best and most flexible water-proofing that can be employed—an important point where any fuze or wire leading from the cylinder is liable to flexure or vibration.

The only precautions that are necessary to be taken with these fuzes, beyond the perfect insulation of the main wire from the water, are that its connection, which is just outside the cork, should be kept out of contact with the surface of the cylinder, and that the cylinder itself should not be washed over with any water-proofing which would insulate it from the water and check the return current. The main wire should also be tied to the cylinder, so as to prevent any strain coming on the fuze or its connections.

The percentage of failures with these fuzes has been exceedingly small. Out of 60 charges lately fired in depths of from 8 to 20 feet of water, and varying in amount from 50 to 450 lbs., there have been only two failures; and these were due probably to defective insulation of the main wire and not to the fuze.

The Magnetic Battery and insulated wire were obtained from the Telegraph Department; the latter is copper of about one-eighteenth inch diameter, coated with gutta-percha. The battery is contained in a box about 14 inches square and 9 inches high. Its great advantages over the Galvanic battery are, that it requires the use of no liquids; it is always ready for use; its power is constant; and it is more compact and less liable to injury. The magnet fuze composition I obtained through the kindness of Lieutenant Wallace, R.E., who employed it in somewhat similar operations on the Hoogly. He had the ingredients prepared, I believe, at the Calcutta Mint, but as it may sometimes be impossible to procure it, it is important to know a substitute. Mealed powder * when moistened to a certain extent is an excellent one. The mode of preparing it is described in the Royal Engineers' Professional Papers before referred to, but may be repeated here. Dissolve chloride of calcium in alcohol till the solution is saturated; steep mealed powder in it till it has thoroughly imbibed the alcohol and with it the chloride of calcium. Dry the mealed

* Could not be depended on during the hot winds or very dry weather.—W. J. C.

powder completely, and preserve it so in a closely stoppered bottle. When required for use, a few minutes exposure to the air will, by absorption, render the powder sufficiently moist for use; this may be known by its showing a tendency to collect together into small granules. It may then be used in precisely the same manner as the sulphide of copper composition. Twelve or fourteen trial fuzes have been fired with this composition in succession without failure, but it has not yet been employed in place of the magnet fuze composition; the trial was considered to prove that it was sufficiently certain for ordinary use. Mealed powder may also be moistened to the proper degree for priming fuzes by simply folding a small quantity in thin cloth, and breathing through it. It is apt, however, to dry too soon, and it is not by any means certain of ignition. Nothing further need be said on the subject of *firing* charges, but it may be added that the charges in common use are 25 and 50 lbs. ones, contained in tin cylinders. For use in depths of 15 feet and less, these cylinders require no strengthening, but for greater depths they should be strengthened with either stays or rings.

It will render this account more complete, to give a few instances of the demolition of Trees, out of the number that have been removed this year.

In December, a large semul tree, lying 200 feet from the banks at a village called Chupree, was removed by blasting. The depth of water at the root, which lay up-stream, was 20 feet, and the current $2\frac{1}{2}$ miles per hour. A number of separate branches spread out under and above water, and were demolished by separate charges of 25 to 50 lbs. of powder. The root and stem gave most difficulty; the latter was however broken by two successive charges and separated and dragged to shore by crab-capstans. The root which spread out in irregular masses to a diameter of 20 feet facing the current, resisted a great number of charges, and several cylinders were broken on its projections; others of the charges broke off portions, but brought other new ones up to the surface. The tree was finally demolished after the expenditure of 850 lbs. of powder. It would have been a manifest saving of time if a 400 lbs. charge could have been placed near the root, but the strength of the current, and the shape of the root, rendered it impossible.* The crab-

* Large boats could not safely be got into position in front of such a tree, and even if they could a cask large enough to contain 400 lbs. of powder would offer such a surface to the current as to be quite unmanageable; in some positions a cask may be sunk by another plan, described further on.

capstans employed were roughly made, but have proved very serviceable. They are a convenient mode of obtaining great power, and a few carpenters and blacksmiths can make up one in a day or two.

In February, a large tree lying near the bank at the village of Tajpoor was removed. The stem was a mass of wood of about 10 feet in diameter, and the same in length. The branches were demolished in the ordinary way, but 50 lbs. charges had no effect on the stem. As its upper side projected above the surface of the water, it was ultimately split up by small charges placed in holes bored in the wood. Here also a charge of 300 or 400 lbs., if effective, would have saved time; but neither was there a good position for one, nor do I believe that it would have had any further effect than to throw the stem a short distance to one side or other, as the wood was perfectly sound, and of great strength.

Near the same place a large tree lying half on the bank and half in water was demolished by a 200 lbs. charge followed by a few small ones. The charge was placed in a cask under a hollow of the tree and in the water; the timber directly over the charge was about 12 feet thick, and embraced a palm tree that had grown with it. The timber around it was completely shattered by the explosion, but the palm itself was unhurt. Here the good effect of the charge was due to the timber being rather decayed, and to the good position in which it was placed.

In February, two trees, each 9 or 10 feet in diameter, were removed from the river at the village of Belthfah. The water was too shallow for the use of large charges. On one of them a few 25 to 50 lbs. charges were first employed, and the stem was lifted out of the sand so as partly to project above water; it was then split up by small blasts placed in the wood, and its demolition completed with 25 and 50 lbs. charges. The other tree was removed in the same manner, and in both cases the fragments, which were large, were dragged out by three capstans working together, and hauled up the main bank by an English gyn. Attempts made at the same place to remove a sunken banyan tree were unsuccessful. The roots resisted several small charges, and ultimately a charge of 165 lbs., and a force of 10 tons applied by means of capstans and cables, had no effect in tearing them asunder.

In February, a large tree lying on the sands above the water level was demolished by means of two 25 lbs. charges, fired simultaneously in the following manner:—From the main wire of the battery, a branch was led *to each charge, and as the cylinders lay in dry sand, whereas a moist connection is necessary to complete the return circuit, the return wires of the fuzes were connected with metal rods driven down into the sand till moisture was reached. To make the connection more perfect, water was poured over each cylinder and the sand round it. The battery was 400 yards away at the edge of the river. The return wire and plate were immersed in the water as usual. Both charges ignited perfectly simultaneously.*

In March a large tree lying in deep water and a strong current at the village of Tickyah, was partially removed. Here also two charges were fired simultaneously, but with little effect; ultimately a charge of 450 ℔s. was sunk and fired in the following manner:—A cask was prepared and tarred, and two rings of hoop-iron were nailed on its ends, so as to project from its sides and allow it to slide down a rod. A bamboo 4 inches in diameter was driven in the best spot available, and the cask was passed on to this by means of the rings; it then stood floating on the water in an upright position and empty, but with the fuzes prepared and inserted. In this case the independent fuzes were employed, as it would have been a difficult matter to recover the cask had one failed. The cask was filled and sunk in its place in a depth of 20 feet, by weights; the bamboo was securely stayed against the tree, and the main wire being connected with one of the fuzes, the boats were drawn away, and the charge fired.* The effect was not so good as might have been expected; some lower branches were separated and the tree was thrown into an upright position, but the stem was quite uninjured. The remaining operations require no notice.

A tree buried in the sand and liable to become dangerous on the shifting of the channel, was attacked in the following manner:—Its position and size were first ascertained with iron sounding rods. The stem was found to be 8 feet under the sand, and 7 feet 9 inches under the water level. A good position being selected, an iron tube 11 feet 6 inches long and 1 foot in diameter, was driven down beside it to a depth of 11 feet by means of a *ringing* engine. The tube was then bored out to a depth of 10 feet with a boring tool 10 inches in diameter, and provided with a leather sand valve. A 50 ℔s. charge was passed down the tube to that depth, and the tube was drawn by a differential pulley hung to the *ring-*

* In this manner the drag of the current on the cask was rendered harmless, and in spite of it, the charge was successfully sunk into its position under a perfect network of branches, in a place where it would have been quite impossible to bring a large boat.

ing engine. The charge was fired by means of a tin tube and pellet fuze but without much effect. It was neither large enough, nor had it been placed deep enough. The tube should have been driven 12 feet deep, and a 100 lbs. charge placed at a lower level than the stem. Time did not admit of repeating the operation, but the more dangerous part of the tree was removed by other means.

In this operation the Ringing engine was worked in the following way:—The rope attached to the ram was passed down, and through a block at the rear of the engine; it was carried a long distance to the rear, attached to a peg, and worked alternately by two parties, one of which took it up when the other dropped it, and the ram had fallen. In this manner nearly double the ordinary number of blows were delivered in a minute, and the men were not fatigued to the usual extent; but of course a double working party was necessary.

A large tree, lying in the sands near a village called Gyaspoor, was removed by small blasts fired in holes made by means of a lever drill. This drill, which was made up out in camp, consisted of an iron frame, carrying a wheel 1 foot in diameter, and working on a vertical axis. The frame was provided with keys for clamping it on a square iron-rod 5 feet long, and pointed at one end. This rod could be readily hammered into the stem of any tree it was required to bore, and the drill clamped to it could thus be brought to bear in any desired direction—vertical, sloping, or horizontal—the axis of the wheel was pierced to carry a square iron-rod, in the lower end of which the drill bits were fixed. The upper end was pointed, and pressure was applied to it by means of a lever clamped at any required height to the rod driven into the timber. The drill was driven from a 3-feet wheel placed in any convenient position; it was capable of boring 3-inch holes with moderate rapidity.

The preceding examples are sufficient to illustrate the mode in which the demolition of trees has been carried out. A few words may now be said on the removal of sunken Kunkur rocks.

The features that these rocks usually present have been already described, and it only remains to state the means that have been employed in attempts to remove them. The first trials were made last year on a small rock of thin kunkur, lying in from 2 to 6 feet of water, and in a strong current. The apparatus employed was a species of small cofferdam of a portable character, consisting of an outer and inner frame and sheeting, and including between them 2 feet 6 inches thickness of strong clay puddle. The space enclosed was a rectangle of 4 feet 6 inches by 3 feet 6 inches, the object being to dry a space sufficient for a miner to work in, and drive a shaft down through the kunkur, in which a large charge might be placed and fired. The outer sheeting of the dam was supported by four frames, rectangular in shape, and each 10 feet by 3 feet 6 inches high, braced diagonally and made of $3\frac{1}{4}$ inches sál scantlings. These frames when bolted together at the angles formed a square enclosure, within which the sheeting was put down vertically in 6 inch widths. The sheeting was supported at the back by longitudinal pieces parallel to the top and bottom rails of each frame, and $2\frac{1}{4}$ inches within them. These pieces could be put in position after the frames had been bolted together.

The inner framing was constructed in the same manner, only smaller, so as to allow the space between the walls required for puddling. The surface of the rock being very irregular and steep, it was necessary to put down the cofferdam in the following manner:—Two boats were anchored over the rocks, and the outer frames previously bolted together so as to from a square enclosure, were let down into the water. A few pieces of sheeting were then dropped in at the angles, and wedged when resting on the rock. The position and stability of the frame being thus secured, the remaining sheeting and the inner frame were rapidly put in, and the puddling commenced. The attempt to dry the dam failed; it was found that the substratum was sand, and the water came up through cracks with which the surface of the kunkur was covered; but there is no doubt that this kind of dam could be used occasionally with advantage where the material to be removed is solid rock or kunkur underlain with clay; it is very portable, and could be put down and taken up much more rapidly than a dam supported by any arrangement of jumpers driven into the rock.

The next attempt on the same rock was made with boring tools of rough construction. A portion of the kunkur in 4 feet depth of water having been broken up, an attempt was made to bore down, through the substratum, with the object of placing a 50 or 60 lb. charge at a depth of 6 feet, or thereabouts, below the kunkur. This attempt also failed from the fact of the sandy substratum being too fluid to retain any hole.

Trials were next made on a rock 80 feet long by 50 feet in width, and partly above water; the substratum in this case being clay, the boring tools proved quite effective. The operation of placing and firing the charges ultimately took the following shape:—A 2-inch iron-bar was first driven down into the kunkur to a depth of 6 or 7 feet, and drawn; into the hole thus formed, a small charge of powder contained in a thin cylinder of tin was inserted to a depth of 6 feet and fired. It was found that this charge by its explosion produced a narrow crater in the kunkur about 6 feet deep, and after clearing the hole with a boring tool about 1 foot in diameter, a 50 ℔. charge was readily placed at a depth of 6 feet under the kunkur, whether under or above water. It made little or no difference in the rapidity of the operation whether the kunkur lay under or over water. The hole having been tamped, the charge was fired with the pellet fuze,* producing a crater of about 18 feet in diameter, and 6 or 7 feet deep. In this manner the rock was rapidly blown away to a depth of 6 feet under-water, the whole operation not lasting more than ten days, and had arrangements been more perfect, this time would have been shortened very much.

In the beginning of the present season, attempts were again made on kunkur underlain with sand, and under 3 feet of water. The following method was now adopted:—Boats were prepared with framing, and planks sufficiently strong to bear a heavy strain; they were anchored over the rock with an interval of a few feet between them, and lashed together by cross-ties. A light triangle was erected on the boat, and from it was first suspended a beam of wood, shod with a heavy cast-iron pile-shoe, and slung from a pulley. This was worked up and down like the ram of a Ringing engine till the surface of the kunkur was completely broken up over a small space. On the spot thus broken up, an iron-tube 11 feet 6 inches long and 1 foot in diameter, was now placed, and driven by a ram slung from the triangle, and worked as before described. When driven to a depth of 7 feet, it was bored out, and a charge of 50 ℔s. placed at a depth of 6 feet under the kunkur. The tube was then drawn with a differential pulley, and the boats being removed, the charge was fired by means of Bickford's fuze, producing a crater 16 feet in diameter and 5 feet deep. The operation occupied about 8 hours, but it was not repeated, because the river was too high at the time to make it of any real advantage except as an experiment. Since that time no operations have been undertaken against kunkur rocks, except the following, which was also purely experimental.

The kunkur beds at Hurdee are the most extensive on the Gogra; they

* This was one of the earliest operations, and no galvanic or magnetic battery was at hand.

lie at various depths, and several rocks jut above the surface, or are just concealed by it when the river is at its lowest level. But whatever their total extent may be, there is no doubt that the removal of about 10,000 square, or 20,000 cubic, yards of the most prominent rocks would greatly improve the channel. It remains to be seen then to what extent the experiments that have been made justify us in supposing that this can be done within a reasonable time and at moderate cost. As in the previous experiments, boats were moored over the rock; this time in from 4 feet 6 inches to 5 feet of water, and a current of more than 2 miles per hour. The other arrangements were the same as before, but as the kunkur here lay to an indefinite depth, and partially mixed with clay, the tube before used was not necessary. A 2-inch iron-bar was driven straight down into the kunkur to a depth of 6 feet, and drawn by means of a differential pulley assisted by block tackle worked from a capstan. The hole thus made was slightly rymed out with an iron tool for the purpose, and a slender sál pile was driven down, deepening and widening the hole to a diameter of 3 inches;* it was rapidly withdrawn, and a charge of 8 lbs. contained in a tin cylinder was pressed down into the hole to a depth of 8 feet. This was fired, and the hole produced, which was as narrow at the mouth as at the bottom, was cleared out with a boring tool 1 foot 7 inches in diameter and 16 feet long; into this a diver descended, and reported that it was about 2 feet in diameter the whole way down and 8 feet in depth. A charge of 60 lbs. was all that was available at the time, and it failed through the breaking of the cylinder; but this failure in no way affects the principle; moreover other charges were fired successfully under the same rock, in the same manner; but this instance is given, as it was the most successful one in the product of a large and deep shaft.

The centre of the above charge was at a depth of 7 feet 6 inches under the surface of the kunkur, and with a further depth of 4 feet 6 inches of water above it. Now, although we have no exact data for the influence of this depth of water, we may presume that it will necessitate a considerable increase of the charge in order to produce the same effect as in air. The charges ordinarily used to produce three-lined craters in earth are calculated as $\frac{1}{4}$th the cube of the Line of Least Resistance, whereas I propose here to employ charges of $\frac{1}{3}$rd cube of L. L. R. On this supposition, the

* In loose kunkur of this description a wooden pile will act effectually as a wedge to widen a hole already formed, but it cannot be driven in the first instance even if shod with iron.

quantity of powder required at that depth to produce a three-lined crater would be 140 lbs; and we may, perhaps, calculate that on an average, charges of 150 lbs. would produce craters of 20 feet in diameter; where the water was deep, they would, perhaps, produce less than this; where shallow, more. Part of the débris from such craters would generally lie about the edges, part would be blown to a considerable distance, and part would fall back into the crater where it would be harmless, being at a considerable depth under the surface. On the débris which lay round the hole, the current would act powerfully, separating the clay and reducing its bulk to less than half the original; the nodules of kunkur themselves would be carried away in the floods, or even if they remained they would be at a much greater depth under water, and could never bind again into a surface as compact as the original. Thus it seems likely that, even were the blasting operations not assisted by dredging, the result would still be to break-up, disintegrate, and reduce in bulk the whole rock, and leave the kunkur in such a condition as to be acted on by the succeeding floods, and to be gradually carried away altogether.

On such an extensive rock surface as that of Hurdee, it would be easy to accommodate three or more working parties,*—we may suppose three,—and it is not too much to assume that, with the proper appliances, each party would fire three charges in a day. Eight charges a day would be a fair allowance for the whole three parties, and supposing such charges to be placed at two-lined intervals, or 14 feet apart, the whole number of charges required to break up a surface of 10,000 square yards would be 462, the quantity of gunpowder about 70,000 lbs., and the number of days in which it could be done 58; but allowing for unavoidable delays and occasional bad weather, it would be well to calculate on the operation lasting three months, which is about the length of the season most favorable for such work.

The cost of the operation may be roughly estimated as follows:—

	RS.
Working parties, including crews of three pair of boats, 20 men each, at an average rate of wages of Rs. 5, .	300
Three Lallas in charge of boats, at Rs. 15, . .	45
Hire of additional boats for carriage of men and materials to and from shore, ...	100
Total .	455 monthly.

* Each pair of boats would take up a considerable space in order to keep the moorings clear of each other.

As experiment has not yet decided how far it would be necessary to assist the action of the charges by dredging away the débris into deep water, the hire of the three boats, at Rs. 30 per month each, will be added to the above :—

	RS.
Brought forward, ...	445
Hire of three boats for dredging at Rs. 30 per month, each	90
Total, . .	535
Total boat hire and labor for three months. . .	1,605

The work would of course require the presence of an Engineer and a European Overseer, whose salaries however will not appear here. The expenditure on materials would be trifling except that on vessels to contain the charges. This expenditure could be reduced to a minimum by employing *either 100 or 200 ℔. charges, in either of which cases, the original* powder barrels would be placed in the mines, and no expense would be incurred beyond that of making them water-proof.

If 150 ℔. charges be employed, as here contemplated, the cost of tin cylinders should be added to that of preparing the barrels, as it would be necessary to employ for each 150 ℔. charge, one 100 ℔. barrel, and one 50 ℔. cylinder.

	RS.
Cost of preparing 462 barrels, at 8 annas each, .	231
462 tin cylinders, at Rs. 1 each, . . .	462
Total, .	693
Making a total expenditure during the progress of the works of	2,298

The first cost of preparations and of a stock would be as follows :—

The boats employed for boring and for placing the charges should belong to Government; but their cost would be a charge only against the first operations, as the same boats would answer for all subsequent ones, as well as for any of the ordinary works of the season. Allowing two 150-maund boats to each working party, at a cost of Rs. 1 per maund of tonnage, the estimate would be as follows :—

	RS.
Six 150-maund boats, at Rs. 150 each, . .	900
Decking and strengthening do., at Rs. 50, . .	300
Total, .	1,200

PLANT.

		RS.
Six 2 feet diameter boring tools, at Rs. 50,	. .	300
Three triangles, at Rs. 50,	. . .	150
Three differential pulleys, at Rs. 100,	. .	300
Three crab winches, at Rs. 100,	. . .	300
Miscellaneous,	. . . .	150
	Total, .	1,200
Grand total first cost of boats and plant,	.	2,400
Grand total cost of labor and materials,	.	2,298

The above estimate for plant does not include jumpers, hammers, Ringing engines for driving the jumpers,* by which are here meant simply pointed bars of iron, not steeled; blocks and some smaller stores, which in this case happen to be in hand at present. Had these to be included, they would increase the estimate by about Rs. 400.

Taking the figures as they stand, and adding 10 per cent. to cover contingencies and the wear and tear of tools and cordage:—

		RS.
The total first cost of boats and plant will be	.	2,640
The total cost of labor, boat-hire and materials	.	2,528

These amounts represent the cost of the operations on a sunken rock, as it would be charged against the sum appropriated for works, and it takes no account of the cost of European supervision and of gunpowder, which would not be so; but where the expenditure of gunpowder is so great, its cost, if it entered the estimate would become by far the largest item. In the foregoing estimate the cost has been worked out by calculating merely from the extent of the surface of rock to be demolished, and it has been tacitly assumed that the charges would in every case reduce the kunkur to a safe depth below the surface. This depth may, and has been assumed as 6 feet, but every additional foot that could be obtained would be of value, and be worth a proportionate increase of expenditure. In order to obtain a clear depth of 6 feet in every case, it would, perhaps, be necessary to use larger mines where the kunkur lay nearer the surface, and smaller where it lay deeper. But it is thought that the average taken, namely, 150 lbs. for each mine, is on the safe side of the truth.

* The jumpers on all the rocks yet tried could be hammered directly down through the kunkur, which of course can be much better done with a Ringing engine than by hand. In the case of block kunkur it would be necessary to work the jumper in the ordinary fashion.

The difficulty previously mentioned, namely, that of entirely dispersing the kunkur thrown up by the explosion of a charge, might be partially obviated by using rather larger charges than those proposed, or by dredging, or by both methods. It is a matter for experiment, as no sufficient data for it exist at present; but it is suggested that it would be economical to work only on the deeper part of a reef according to this method; and where cofferdams could be constructed, to employ them for the removal of all rock within 2 feet 6 inches or 3 feet of the surface, as in such shallow water they would be readily and cheaply constructed. Cofferdams appear to have been employed on the Ganges river works with a certain degree of success, but at an enormously greater cost than that here estimated; there are also certain objections to their use, which cannot be gone into here, and many of the rocks spoken of have a sandy substratum which would not admit of their employment.

The above description and estimate will answer their purpose, if they be considered to show the feasibility of removing kunkur rocks on a large scale at a reasonable cost. On such a scale as here contemplated their removal is—by the ordinary methods of blasting—by no means a simple engineering problem, and an inspection of the rocks themselves, with masses jutting up here and there and the current racing over sunken beds between them, is not at all calculated to re-assure the Engineer, who has not at the time decided on his means of attack.

W. J. C.

No. CXV.

THE HURROO BRIDGE—LAHORE AND PESHAWUR ROAD.

Designed and Constructed by LIEUT.-COL. A. TAYLOR, R.E., C.B.

THE Bridge consists of 10 spans of 40 feet each. The piers and superstructure are of timber; the abutments of rubble masonry. The depths to which the different piers and abutments are carried are shown in the drawings. The timber work throughout is of heart of deodar, all sap wood being rejected.

Piers.—Are shown in full detail in the drawings. Every timber is in one length, excepting only the waling pieces on the pile heads. The lowest pairs of horizontal waling pieces are reduced to 10 × 6 scantling, to admit of timber of the required length being obtained from the Cabool river. The bolts are throughout of round iron ¾-inch diameter.

Abutments and Wing Walls.—Are founded at the depths shown, and are built of coursed rubble with the following exceptions:—The wheel-guards are of cut bricks-on-edge, and the parapets are furnished with a cap of cut brickwork, 6 inches thick, laid on edge.

Superstructure.—Corbels on pile heads are 12 inches wide and 10 deep, and are firmly bolted to the tie-beams, each by two bolts of ¾-inch round iron.

The Beams are 10 × 6 scantling, except the last length at each end resting on the abutments, which is 10 × 9, to give depth sufficient to admit of the abutting blocks being countersunk into it to a depth of 3 inches. No joint in a tie-beam within 6 feet of a pier; the drawings show in detail how the joints are made. The pieces all abut against each other with square ends; the keys are of seasoned seesum. Each tie-beam is supported by two ½-inch iron rods.

Vertical Posts over Piers.—Details are given in the drawings.

Straining Beams are secured to the roadway beams by four trenails of 1½ inches diameter of dry khow wood.

Roadway Beams.—Scarfs in roadway beams are made in the places, and in the manner shown. Details are given in the drawings.

Roadway Planking.—The planks supporting the railing struts are 6 inches thick, no piece being less than 9½ feet in length; they are secured to the roadway beams by spikes 11 inches long. Remainder of planking 4 inches thick, secured by spikes 8 inches long. Each end of every plank rests on a beam and is secured to it by two spikes; elsewhere one spike secures each plank to each roadway beam. The lengths of planking break joint throughout.

Wheelguards are in long lengths, of 10 × 8 scantling. The different lengths abut against each other in each case over a block with square ends, and are kept in position as shown in figure. The hard wood key is of seesum or khow wood.

Wall Plates on Abutments.—The tie-beam is notched out 1½ inches to receive the wall plate.

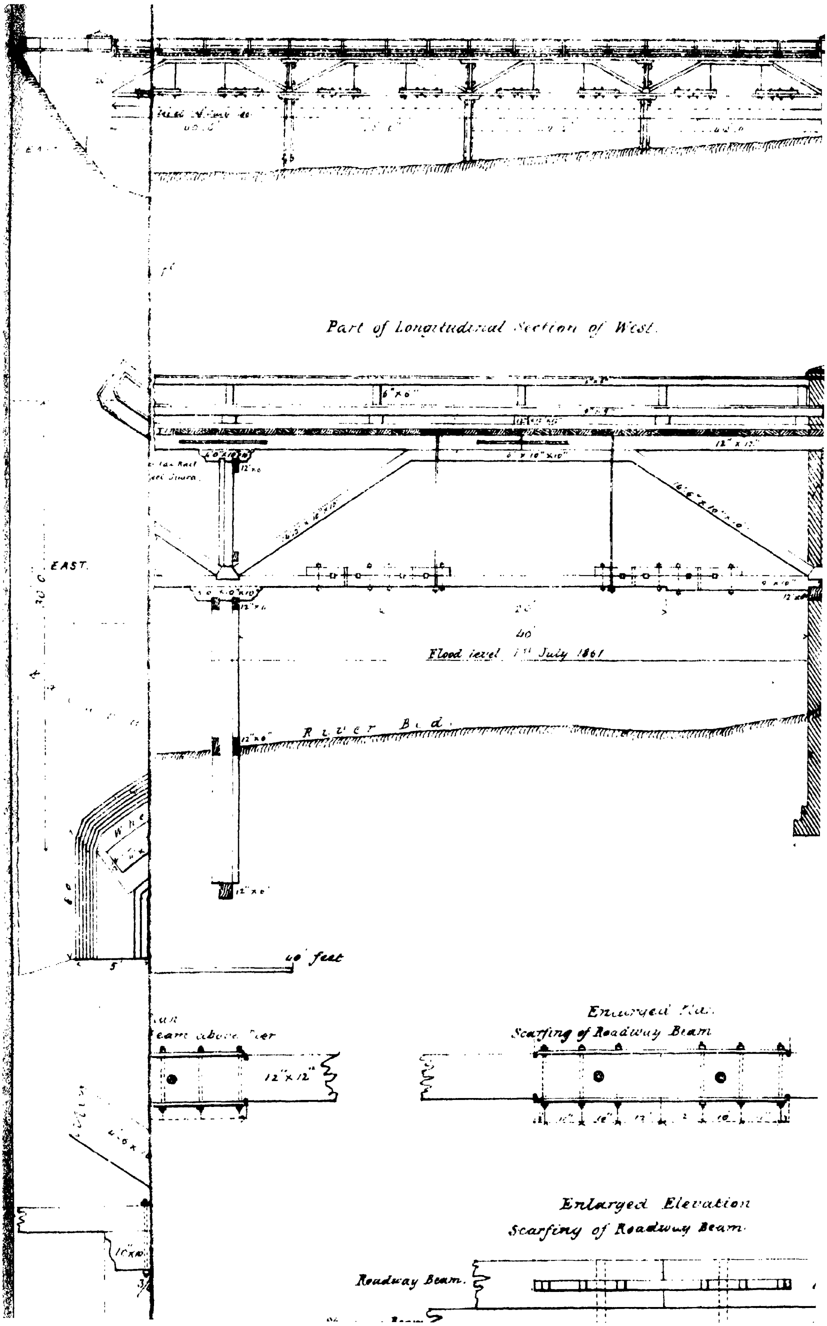
Metalling is of broken stone.

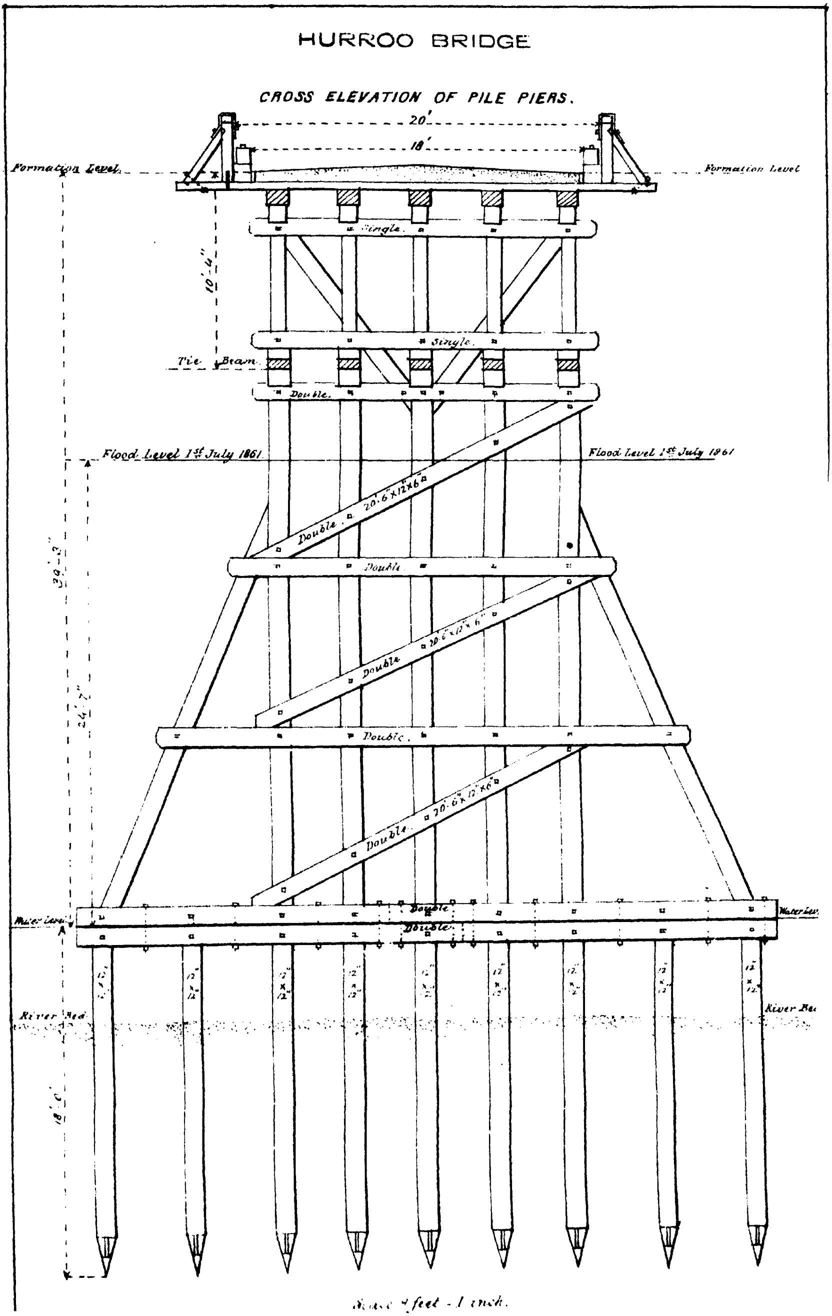
Painting.—The railings, including verticals and struts, are painted in three coats of white lead and oil.

Tarring.—The wheelguards, wheelguard blocks, roadway planking, on both sides, and all woodwork, thence to water level including wall plates, and all touching surfaces, are payed over with pine tar.

Abstract of Estimate.

c. f.		Rs.
187,188	Earthwork, excavation in boulders, at Rs. 6 per 1000, ...	823·128
10,480	„ „ in sand-stone, at Rs. 10 per 1000, ...	104·800
33,725	„ filling in and ramming, at Rs. 5 per 100, ...	168·625
21,416·42	Pucka rubble masonry with cut-stone faces, at Rs. 19 per 100,	4,069·119
239	Brickwork, at Rs. 26 per 100, ...	62·14
13,325·4	Deodar wood work, at Rs. 2 per cubic foot, ...	26,650·8
98·55	Hardwood work, at Rs. 4 per cubic foot, ...	394·2
mds.		
17,095·56	Iron-work, at Rs. 18-12 per 100, ...	3,205·417


Part of Longitudinal Section of West.
6" x 6"
12" x 12"
6" x 10" x 10"
EAST.
20'
40'
Flood level 1st July 1861
River Bed.
12" x 6"
40' feet
Enlarged Plan
Scarfing of Roadway Beam
12" x 12"
Enlarged Elevation
Scarfing of Roadway Beam.
Roadway Beam.
10" x 10"


HURROO BRIDGE
CROSS ELEVATION OF PILE PIERS.
20'
18'
Formation Level
Formation Level
Single.
10'-4"
Single.
Tie Beam
Double.
Flood Level 1st July 1861
Flood Level 1st July 1861
Double 20'6"×12"×6"
Double
39'-3"
Double 20'6"×12"×6"
Double.
24'-7"
Double 20'6"×12"×6"
Water Level
Water Level
Double
Double
River Bed
River Bed
18'-0"
Scale 4 feet = 1 inch.

ABSTRACT OF ESTIMATE.—(*Continued.*)

s. f.		Rs.
76,398·94	Tarring, at Rs. 2 per 100, ...	1,527·978
3,016	Painting, at Rs. 5 per 100, ...	150·800
46	Driving piles at Rs. 15 each, ...	690
	Total Rupees, ...	37,847·007
	Add contingencies, at Rs. 5 per cent., ...	1,892·35
	Total,	39,739·357

ATTOCK,
8th *January*, 1862.

A. T.

No. CXVI.

MANUFACTURE OF IRRIGATION PIPES.

Memorandum on Machine-made Earthenware Pipes for Irrigation.

By Capt. W. Jeffreys, R.E., *Exec. Engineer, Ganges Canal.*

The complete adaptability of earthen-ware pipes for all purposes of irrigation and drainage may now be considered an established fact. To meet a want so universally felt, steps have been taken by the Government for promoting and developing the growth of this useful description of manufacture. Potteries have been established at certain stations, and the services of professional hands have been obtained from England. We may then safely predict that the day is not far distant when they will come into general use.

The object of this paper, which relates more especially to the employment of earthen-ware tiles for irrigating purposes, is to show the results of the first experiments of the kind which have been made in these Provinces. But before proceeding to consider the processes employed in their manufacture, it is necessary to say a few words on the causes which led to their adoption in the Irrigation Department.

On all canals it has been found necessary to regulate the quantity of water supplied to cultivators, by constructing in the banks of *rajbuhas* (minor irrigating channels) outlets of a fixed section, the size depending on the area it is designed to irrigate. For this purpose wooden boxes or covered-in troughs, (termed *colabas,*) embedded in the rajbuha bank had been used for many years past in these Provinces; but their employment is open to the following objections:—

I. Their great original expense, the cost of each colaba varying from Rs. 5 to 8 each.

II. The necessity of their frequent renewal. For in order that they might be as cheap as possible, common wood such as jamun, semul, mangoe, and others, were used in their construction. They were unseasoned and of a perishable nature, and the consequence was that new colabas had to be supplied yearly; this was a heavy tax on the cultivators.

III. For the same reason, that of economy, the workmen nearest at hand (frequently unskilled) were employed in constructing these colabas. They were consequently ill made, of varying section and apt to leak; the result of which was an irregular supply of water, serious breaches in rajbuha banks, and loss both to Government and the cultivators.

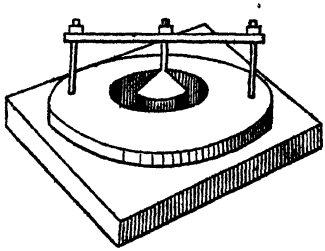
IV. In consequence of the yearly renewal of colabas, cultivators came to regard their water-courses as temporary channels, and on receipt of a new colaba often shifted their heads to suit their convenience. Little care was therefore taken in the construction of these channels, which are still in a lamentable state causing everywhere percolation and great wastage of water.

To remedy these evils earthen-ware tiles were first introduced by Mr. Macrone in the Allygurh Division of the Ganges Canal, in 1862. They were thrown and moulded on a potter's wheel and were burnt like tiles in an open clamp. They were made in three sizes, of 8½, 6 and 4½ inches in diameter, respectively. The cost of each joint was from 2 to 2½ annas, so that for 10 joints which were required to traverse the bank of an ordinary rajbuha, a cost of Rs. 1-4 only was incurred. When embedded throughout in lime, 3 inches in thickness, they were found to be tolerably durable; and many can now be pointed out, which have been in use from two to three years without any apparent deterioration. The great advantages derived from the use of earthen-ware tiles, both for economy and durability, soon led to their adoption in other divisions, and it is now believed that the manufacture of wooden colabas has been altogether discontinued.

Although an improvement on the old box, the tiles made by native potters are still very defective. They are necessarily crooked and are not of uniform size throughout. They are but imperfectly burnt, and being porous, they cannot resist the action of water, and must in course of time decompose. A perfectly true sound glazed earthenware pipe would remove all the evils above alluded to, and would be useful, not only for irrigation outlets, but for all purposes of irrigation and drainage to which it may be applied. To attain this object, a manufactory was established at Nanou with a view of making experiments, the results of which are embodied in this memorandum.

The moulding machine consists of a strong wooden vertical cylinder, 5 feet 6 inches in length by 20 inches in diameter, supported on beams firmly embedded in masonry. It is constructed of well seasoned seesum, 3 inches in thickness, secured on the outside with four iron bands, ½-inch in thickness. In the cylinder is a piston worked by a wooden screw, 8 inches in diameter, and at the lower end is inserted a dod or die of the following shape.

The clay, after being previously prepared and worked up to the required consistency, is thrown into the cylinder and pressed out of the dod by the action of the screw. The clay as it escapes is evidently moulded into the form of a pipe.



Below the die is a moveable platform balanced by means of weights attached to ropes running over pulleys, and arranged in such a manner that the resistance offered should just be overcome by the descending clay. When the necessary length of pipe is attained, the action of the screw is stopped; the pipe is cut off with a piece of thin wire and removed to the drying sheds. Being relieved from the pressure of the clay, the platform ascends to its former position, and the operation is repeated. The cylinder full of clay contains twelve 8-inch pipes. In this manner 250 to 300 can be taken out in one day.

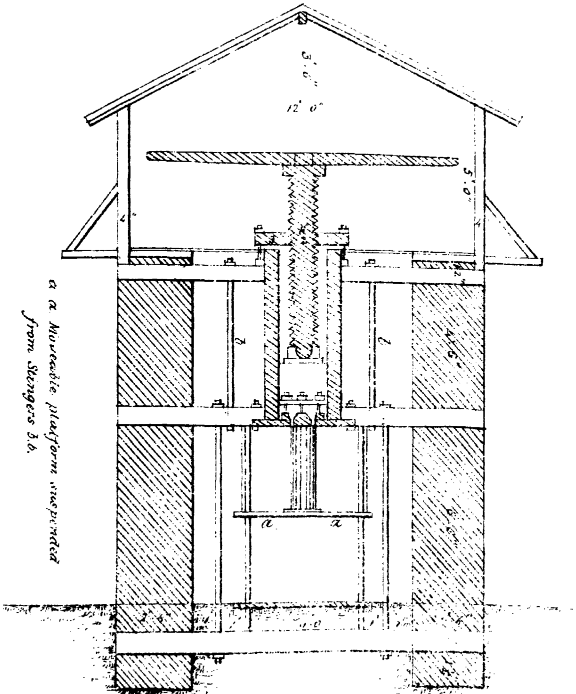
The pipes are then kept from four to five days under sheds to dry; if exposed to the sun or wind, they crack or lose their shape.

Appended is a sketch of the furnace used for burning the pipes. It has six arched furnaces radiating from one centre, enclosed under a conical shaped dome, 18 feet in diameter; it is supplied with four air holes at top and six fire holes below, as well as two doors. The pipes are stacked in an upright position as closely as they will lie, one course above another, and as the body of the kiln is filled, the doorways are built up with kucha or refuse bricks.

From continued experiments made at Nanou, it was found that it requir-

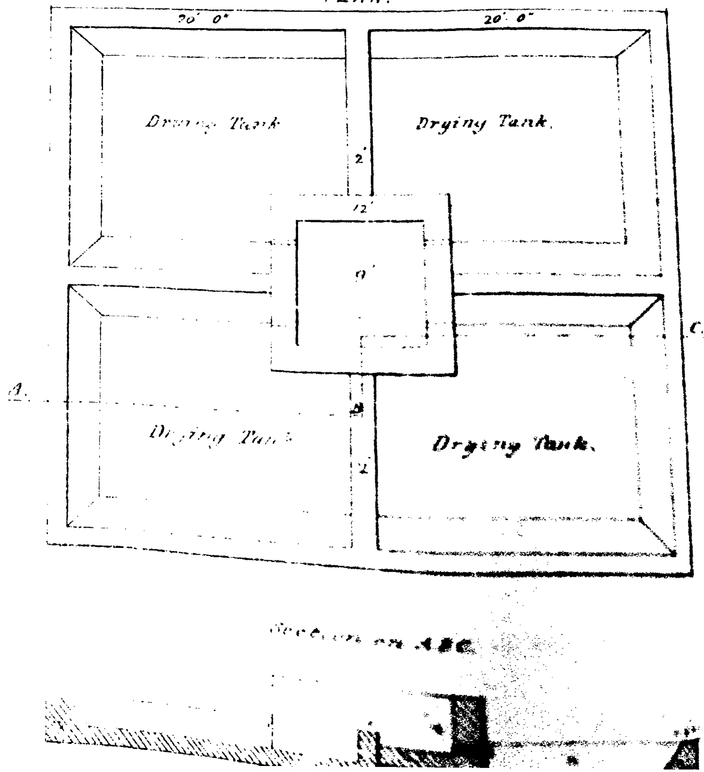
MANUFACTURE OF IRRIGATION PIPES.

Section of Tile Making Machine & House



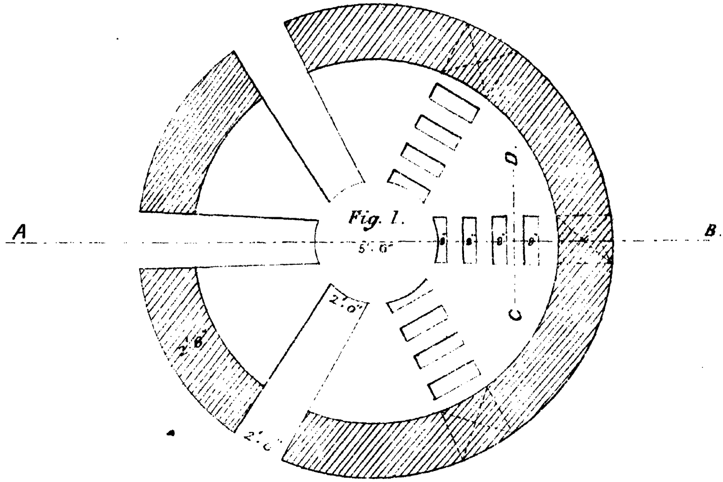
Scale, 6 = 1"

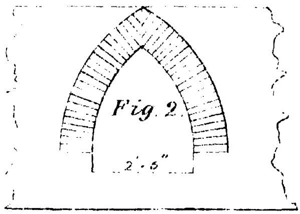
PLAN.



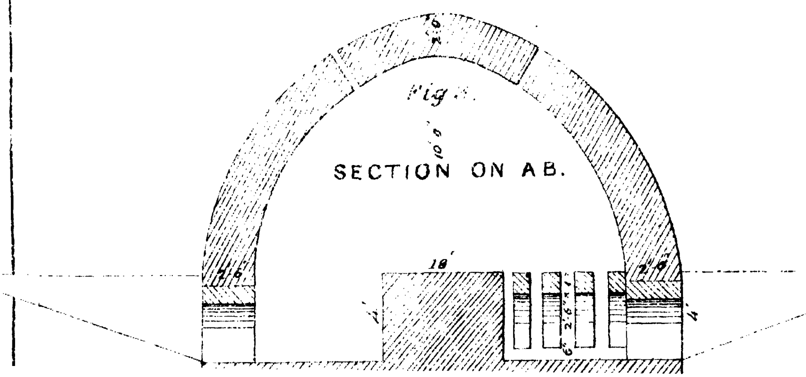
MANUFACTURE OF IRRIGATION PIPES.

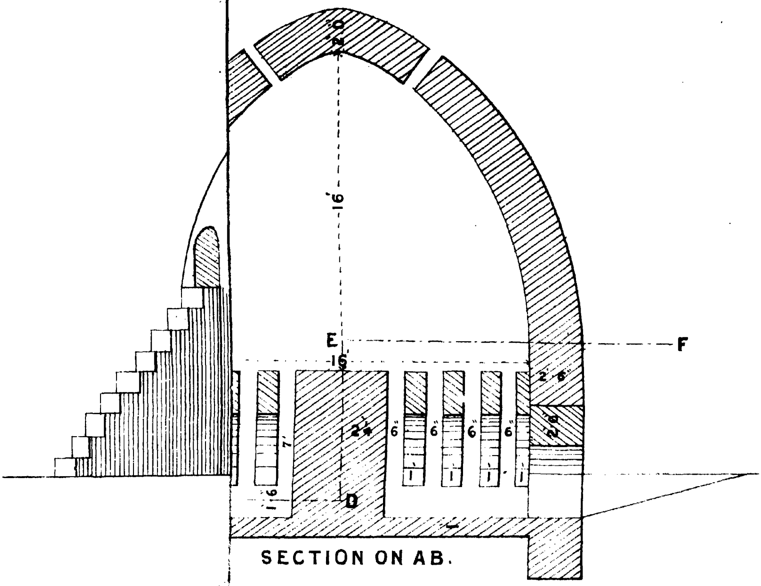
Sketch of Kiln at Nunou for burning Tiles.



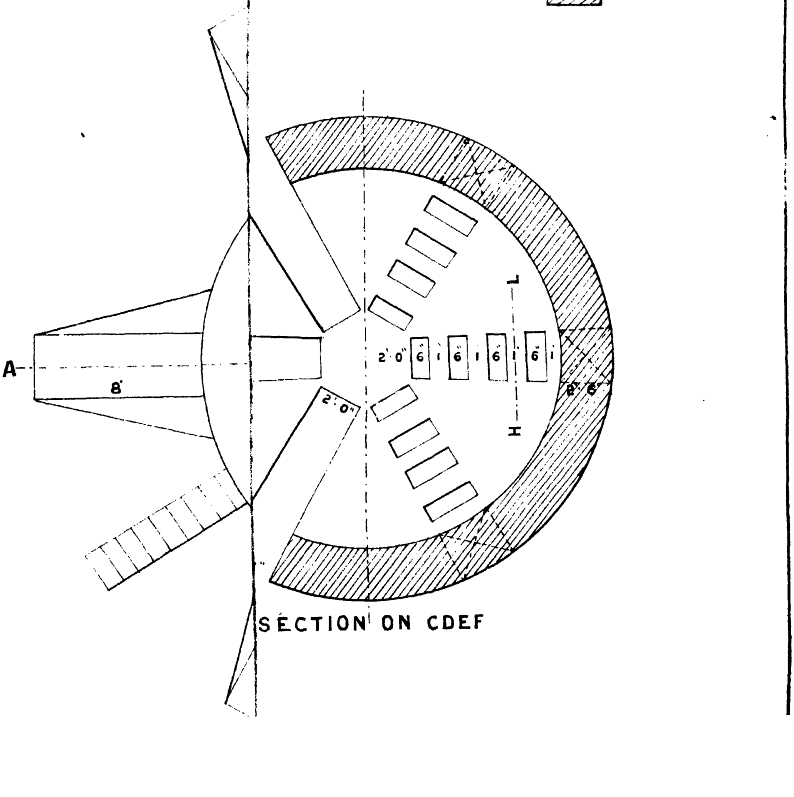


SECTION ON C D.





SECTION ON AB.



SECTION ON CDEF

tions of 8 men were required to force the clay out of the die, producing a pressure on the clay of nearly 10 tons.

The last point for consideration is the size of pipe best adapted for irrigation outlets. This must in a great measure depend on the areas they are designed to irrigate, and the distance to which it is intended to carry the water. The sectional area of the *paimana* in use under the old contract system is ·4 of a foot, which was calculated by the late Colonel Baird Smith, to give under ordinary head pressure a discharge of 1 cubic foot per second. Although irrigation by contract has almost entirely disappeared, it was thought advisable to adopt this size as a standard in making our first pipes.

The sizes were accordingly fixed as follows:—

Large	diam.,	·708 feet,	or 8½ inches nearly	(sectional area, ·4 of a foot)
Small	„	·499 „	or 6 „	(„ ·2 „)

A greater number of the smaller size were used, but in many cases they were found to furnish an inadequate supply of water. I am inclined to think that an intermediate size of 7½ inches (sectional area ·3 of a foot) would be the most generally useful. It would be as well however to have at least three different sizes, in order to meet the several circumstances under which they may be required.

The sizes proposed then for adoption are—

No 1.	Diam.	·708 feet,	or 8½ inches	(sectional area, ·4 feet)
No 2.	„	·617 „	or 7½ „	(„ ·3 „)
No 3·	„	·499 „	or 6 „	(„ ·2 „)

W. J.

16th January, 1866.

No. CXVII.

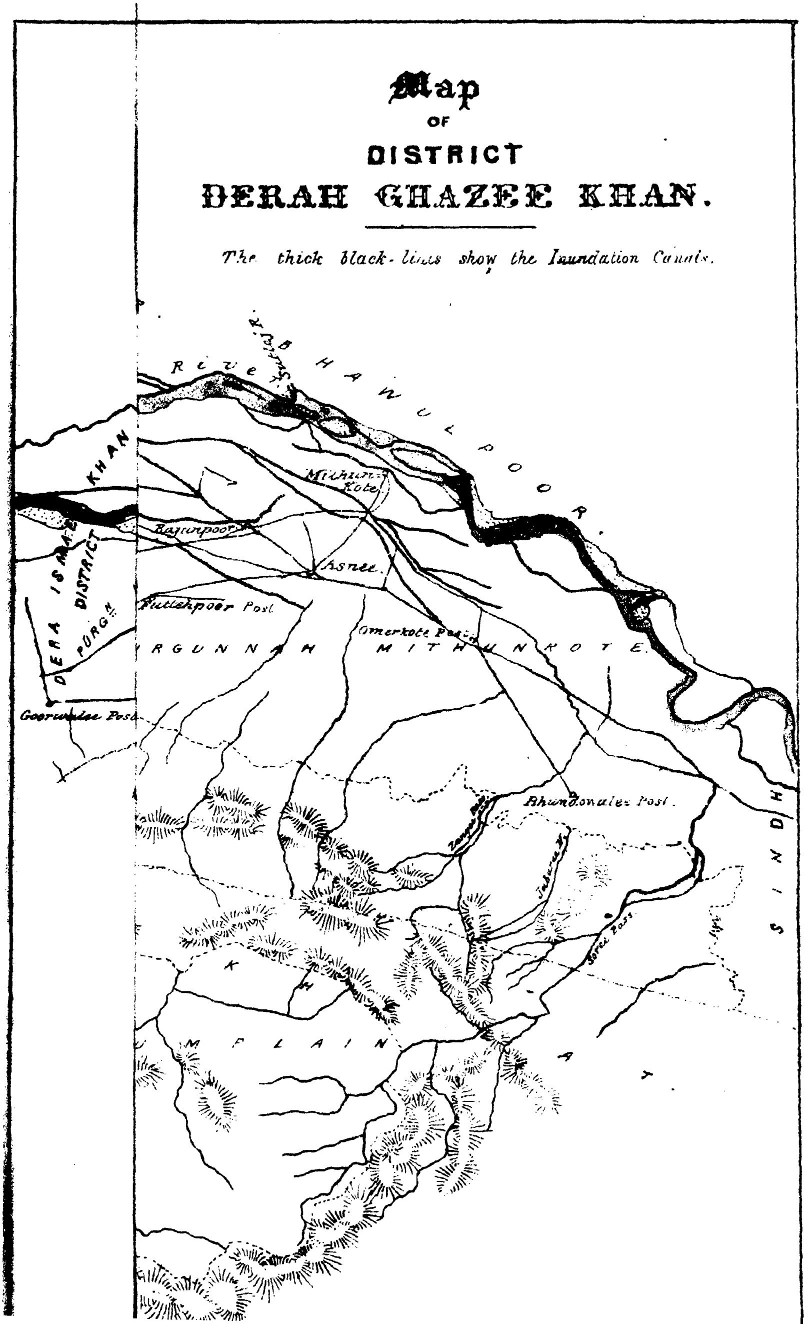
ENGINEERING IN THE DERAJAT.

BY THE EDITOR.

THE Deraját is the name given to a narrow strip of country lying to the west of the Indus, between that river and the Suleiman mountains, which form the boundary of our N. W. Frontier in that part of the Punjab; and is bounded by the Bunnoo District and the Sindh Frontier on the north and south sides, respectively. This tract of country includes two districts, those of Dera Ghazee Khan and Dera Ismael Khan, and measures 250 miles in extreme length, with a breadth varying from 15 to 50 miles, as the hills approach to, or recede from, the river.

The physical aspect of the country is peculiar. In the more southern district the river runs between low banks which are inundated during the rains, and where canals have been cut conveying the water for some distance inland, to irrigate the autumn crops. In the cold weather the river falls and these canals are left dry, their beds being then cleared of the large quantities of silt carried in by the flood waters. But the soil is left rich and moist for the cold weather crop; well irrigation supplies the place of the canals, and a little rain usually falls about February. This part of the country is therefore well cultivated and fairly peopled.

But this description only implies to a small area. As we travel north, the river bank is so high that these inundation canals are impracticable; and again, as we leave the river and approach the hills, the level country soon disappears, and we meet a plateau rapidly sloping from their


Map
of
District
Derah Ghazee Khan.
The thick black-lines show the Inundation Canals.
River
Sutlej R.
Bhawulpoor.
Mithun-Kote
Rajunpoor
Futtehpoor Post
Omerkote Post
Purgunnah Mithunkote.
Bhundowalee Post.
Goorwalee Post
Dera Ismael Khan District
Sindh

foot until it meets the valley of the river. The whole of this upland country forms a strange contrast to the lowlands near the Indus. The soil is a hard stiff clay, stoney near the hills and intersected by numerous dry torrents,—the climate is one of the dryest on the earth's surface, the annual fall of rain being probably about 5 inches,—and the wells are so deep ere the water-bearing stratum is reached, that their construction is expensive, and they can only be very partially used for irrigation.

The soil is too heavy for wheat, and a scanty crop of millet (jowar and bajra) is about the only thing produced. Villages are few and far between, and a coarse scrubby jungle takes the place of trees. The hills themselves are barren and desolate, but in their interior lie more promising valleys, nourished by occasional springs; and here resides a lawless population, who think cattle-lifting more respectable than agriculture, and are always ready for a raid into the plains through the mouths of one or other of the Passes.

A road runs parallel to this dangerous frontier at a short distance from it, and connecting a chain of military posts held by detachments of the Punjab Frontier Force. In support of these forts are the cantonments of Dera Ismael Khan, Dera Ghazee Khan, and Rajunpore, built in the more civilized country near the banks of the river.

For some years after its occupation by the British in 1849, the whole Trans-Indus country was a veritable *terra incognita* to the rest of the Punjab. No ladies were allowed to reside there—English soldiers were unknown, and as there was little to attract anybody in the way of sport, scenery, or antiquities, the country had very few visitors. But to those whose duties compelled than to reside there (among whom was the present writer), the very isolation of the country and the desolation of its aspect had something of a charm. The inhabitants were a fine, manly race, and there was so much to do in the way of physical improvement that the district was interesting enough to an Engineer. There was not a map of the country in existence, nor a mile of road, while the soil was either parching with thirst or being deluged with water. The irrigation canals which formed the very life blood of the district were unsurveyed and in bad order, while many had become choked with silt and had fallen into disuse—the water of the hill streams was turned to little or no account—and the lowlands were subject to severe inundations from the river. The population was scanty and laborers few; while the natives of other parts looked on the Trans-Indus region with dread, and could with difficulty be induced to cross the river. There was not a wheeled vehicle in the whole district, camels being the sole means of carriage.

The first thing to be done was to survey the country and prepare a tolerably correct Map, which was completed in the cold weather of 1853-54. The work was executed by means of polygonal traversing with the theodolite, the details being filled up by the prismatic compass and chain by means of Native surveyors. The map made no pretensions to scientific accuracy, but it showed with sufficient correctness, the course of the river, the lines of canals, and the positions of the principal towns and villages. The survey was necessarily bounded by the frontier road, as it was impossible to penetrate into the hills without an armed force.

The Canals being mapped, various projects were submitted for their extension and improvement, the objects kept in view being to straighten their course so as to lesson the sluggishness of their current and prevent the deposit of silt at the bends—to remove the spoil banks formed by successive clearances further back from the edge—and in several cases to provide new mouths instead of old ones abandoned by the river. It did not appear feasible to design head works of masonry, as such works might be rendered useless by a sudden shift of the deep channel of the river, and might themselves tend to cause such shifts by accumulating and attracting silt. The breadth of the valley of the river, and the consequent immense cost of the operation, prevented any idea of an *anicut* being entertained for the present, by which a perennial supply of water might be secured for the canals. Most of these projects and others allied to them in character, have since been gradually carried out by the present Executive Engineer (Mr. D. Kirwan), then the writer's Assistant, by which the prosperity and revenue of the district have been very greatly enhanced.

A system of forced labor existed for many years for the annual clearance of these canal channels in the cold season, whereby the zemindars were bound to contribute a certain number of workmen, requiting their services with food only. The Government contributed an equivalent in money, but took no cess for the use of the water which was free to all through whose lands it ran. This system has I believe since been modified.

The Hill Streams on which the scanty population at a distance from the river depended for whatever artificical irrigation they had, varied much in size and section of channel. From two only, small perennial streams flowed, and it was curious to see how under the magic influence of these insignificant rivulets, villages had sprung up, smiling harvests waved and trees nestled to their banks; these oases in the desert serving to show that want of water alone prevented the whole district from being a fruitful garden. But the casual torrents of water in the (otherwise) dry hill streams were carefully turned to account. Dams of earth, stones and brushwood, were thrown across their dry channels in readiness for the possible rain, and irrigating channels carefully led from above their sites to the surrounding fields. The furious torrent might burst these flowing barriers in an hour or less; but that short delay had sufficed to turn a supply of water into the dry channels, and below the first dam, a second, third, or fourth was ready to detain the impatient water, and compel it in like manner to leave a portion of its volume for the irrigation of the thirsty soil. Often in this dry climate was the headstrong but welcome guest looked and waited for in vain, while the seed already sown withered and died; not seldom did it come down with such irresistible fury, that dam after dam was swept away too quickly for any portion of the precious fluid to be secured. The sites and strength of these dams had been settled by custom and ancient prescription for many years, and attempts on the part of any zemindar to erect new ones, or render the upper ones unduly strong, led to fierce affray and bloodshed, often terminating in loss of life.

Some of the most promising of these torrents were surveyed, and designs submitted for storing up the water in a more systematic manner, either in tanks formed by damming up the gorges of the passes, or by permanent dams in the streams themselves, thus forming a series of still water reaches at different levels. These were recommended to the notice of Government as experiments well deserving a trial, but the troubles of the Mutiny came on, the writer had to leave for the seat of war, and the projects have, I believe, since been in abeyance.

So complete was the absence of Roads in the district, that the troops marching down in the relief of 1852, had to take guides with them on (what should have been) the main line of road,—and the country was too poor to afford the expensive embanked roads that would have been required over the greater portion of its extent. But a commencement was at least made, and in conjunction with the civil authorities, a system of roads was designed and proper alignments chosen, which should be gradually worked up to as funds were available. This system comprised—1st, A main line of road running the whole length of the two districts, from their northern boundary to that of Sindh on the south, generally parallel to the river, and to the frontier military road near the hills. This line passed through the principal towns, and was chosen so as to ensure halting places for travellers at convenient distances; 2nd, A series of cross roads connecting the Frontier, with the main district, road, at places of the most consequence on each. These roads were laid out from the map, or by means of special traverses made from place to place; they were then cleared for a breadth of 20 or 30 feet, and inequalities of surface tolerably levelled, while temporary wooden bridges were made over the canals. Where the jungle was very thick it was cleared for some distance on both sides of the road. As money was not forthcoming to raise these lines clear of inundation, many of them were annually flooded and repaired immediately after the subsidence of the river. For the passage of the dry hill torrents, the sides were sloped down and paved causeways in some cases substituted as a cheap and efficient makeshift in lieu of bridges, which would have been practically not required for more than perhaps ten days in the whole year.

The Military Forts on the Frontier* were from 10 to 16 miles apart, and consisted generally of a square redoubt enclosed with a mud wall and ditch, and containing barracks for the native soldiers. In one corner was a high square tower which could be isolated from the rest and served as a Keep, to be held if necessary by half a dozen men; it contained the magazine, provisions and water for the garrison. The largest forts were 85 yards square, and were garrisoned by 40 sowars and 20 infantry; the smaller were 50 yards square, and were meant for 25 sabres and 12 bayonets; no artillery was mounted in any of them. The wells in these forts from which the supply of water is derived, are often of great depth; one, a very old well, measuring not less than 220 feet to the water's surface, and another 150 feet. The water of the latter has so bitter a taste that horses will not at first touch it, and this is a characteristic of many wells in this part of the country. I have seen three in a row containing sweet water, and three in another row, scarce 200 yards nearer to the Hills, whose water, though clear as crystal, had a strong saline flavor.

The Deraját contains three small Cantonments, from which the frontier

* *See* the Koorum Frontier Out-post, No. 8 of these papers.

garrisons are supported and relieved; Dera Ismael Khan on the river's bank to the north; Dera Ghazee Khan, also on the river, 120 miles lower down; and Rajunpore, 70 miles still lower, and some few miles inland. The barracks and private houses are generally built of sun-dried brick, which lasts well in so dry a climate; while burnt bricks are expensive, owing to the cost of fuel.

The River Indus, which forms the boundary of these districts to the east, is here a broad, shifting stream, with a sandy bed. The general slope of the bed is about 1 foot per mile, and the minimum cold weather discharge as taken a little above Dera Ghazee Khan is about 14,000 cubic feet per second. At Mittunkote, 70 miles lower down, is the junction of the Punjnud, which contains the united waters of the Sutlej, Beas, Ravee, Chenab and Jhelum. The place, one would think, should be of considerable importance, but Mittunkote is a very small town, or rather was so, for it has since been swept away by the river. The navigation of all these streams is difficult and precarious, owing to the constant shifting of the deep channel, and the districts through which they all flow are poor and thinly populated. Steamers however now go up to Kalabagh, the first rapids where the Indus breaks through the Salt Range, but the bulk of the traffic (which after all is small) is carried in native flat bottomed boats of from 400 to 1000 maunds. A strong south wind blows pretty steadily during the hot weather, greatly assisting the up-stream navigation at that time; in the cold weather there is nothing for it but tracking.

Besides shifting its course and throwing up sandbanks year after year, the river also cuts away its banks very much, and has swept away many a village, and more than one town in this manner. Dera Ismael Khan was seriously threatened about five years ago, and a very interesting series of works was carried out by the Executive Engineer (Mr. Hubert Garbett), which has had the desired effect of diverting the set of the stream, and for the time at least has saved the town and station. Wherever the banks are low, which is the case generally below Dera Ghazee Khan, they are inundated by the river in the rains for a width of a mile or more, the water being checked from further advance by the high canal banks or earthen dams specially constructed. The inundated land is however covered with a rich deposit of silt, and bears abundant wheat crops in the cold season.

A more serious and extensive Inundation however had established itself annually at the time of my arrival in the district, which required some

Engineering skill, and a very heavy expenditure to deal with properly. Twenty miles above Dera Ghazee Khan the river had made a set inland, and a considerable body of water passed through the heart of the district, and interposing between the town and the hills, held a course of 60 miles in length before it rejoined the main stream. The cantonment was not only isolated from the military posts that it had to support, and only saved from destruction by two canal banks which had been repaired and strengthened; but some 500 square miles of the best land of the district was swamped, while the destruction of villages, crops and cattle was very serious—the remissions of Government revenue in one year amounting to Rs. 28,000. It seemed probable too that unless checked, the action of the water would form for itself a regular channel, and the whole of the Indus might take the same course.

Having taken the necessary surveys, and carefully inspected the site, both during and after the flood, a project was accordingly submitted and duly sanctioned. It did not seem likely that any operations on the river with a view of diverting its course would be effectual; they would at least have required to have been continued for several years—they would have cost a large sum of money, and the result would after all have been doubtful. It seemed better, in presence of the immediate and increasing danger, to carry an earthen embankment across the mouth of the inundation, so as to shut it out and turn it back at the site of its exit. The difficulties attending this were the limited time and labor available for the work—the danger of the river's cutting away its bank and eating up to the toe of the bund; while, if carried too far inland, the water in its descent into the valley would accumulate in force and depth—the necessity of crossing two canals without interrupting irrigation and the danger of attack from hill streams in the rear. Nor did any one of these dangers prove imaginary.

The project having been sanctioned, no time was lost in carrying it out. A thousand laborers were imported on monthly wages from Hindustan and the Punjab, and the Civil Officer lent assistance in collecting labor from the district. In raising the embankment much use was made of a simple machine called the *khen*, or scoop, which is also employed for the same purpose in America. It consists simply of a piece of board about 5 × 3 feet, made slightly concave, with a handle on the upper edge, and attached at the two sides by ropes to two bullocks. The ground being first loosened by the common plough, the lower edge of the *khen* is pressed into the soil by the driver's weight, and the bullocks then drag the earth so collected to the side of the bund, where by simply turning over the *khen* on its edge, the earth is deposited.

The length of the embankment was 12 miles, and it varied in height from 1 to 10, or 12 feet; the width at the top was 5 feet; the slope on the water side only 2 to 1; it should have been much more. No turf was available to protect it, and the soil in many parts was a stiff clay liable to crack; all that could be done to consolidate it was to ram it carefully, layer by layer. The two intervening canals were crossed by masonry sluices, the piers of which were built upon wells in the usual way.

The work was barely finished before the river rose, and aided by a strong wind breached it in several places. One or two of the breaches were successfully closed, but the force of the water prevented it in most cases, and all that could be done was to defend the broken ends by spurs and brushwood piling, which was done very successfully, so as to render the amount carried away a minimum. In spite of the breaches, eleven in number, the benefit caused by the embankment was very sensible, the extent of the inundation having been very much lessened. In the following cold weather therefore, the breaches were closed and the whole work strengthened, and the first rise of the river was successfully kept out. In August, 1856, however, heavy and continuous rain caused an inundation higher than had been known for very many years; and which at the same time brought down the hill streams in torrents from the rear. Thus attacked in front and rear, the bund was again breached in several places, and the force of the inundation was so great that part of the cantonment of Dera Ghazee Khan was swept away, and the city itself flooded. For three days the whole population was cooped up in the fort, which was built on very high ground, where they remained until the waters subsided. Communication with the frontier forts was completely cut off, and the loss of property and even life was heavy—the villagers had in many places to take temporary shelter in the date trees where they constructed *muchans*, and remained there until boats were sent to take them off. Very extensive repairs were needed at the embankment; and, fortunately, the inundation during the following year being lower than usual, gave the new work time to consolidate. Since then the work has stood well, and has effectually answered the purpose for which it was designed. The total cost was rather more than a lakh.

One or two practical lessons were learnt during this contest with the river, which it may be useful to record for others in similar cases. The great difficulty of all such works consists in the want of time for the new earth to consolidate before being attacked. No artificial means are so effective as natural consolidation, but it is possible to some extent to lessen the danger. The water-slope should be laid out at an inclination of *at least* 4 to 1: and it is worth going to a very considerable expense to defend this slope artificially. Grass is often not available; or, if at hand, it will not grow at all in some soils; nor in any, without being watered at first, which is often very expensive. It is, however, the very best protection to the slope; but where not available, twisted grass-ropes, as used in Holland, laid in long pieces and pegged down, are good, and are generally procurable; or large coarse mats may be employed. Such materials will of course not last more than one season, but that is really all that is wanted. By that time, if there has been a little rain, the earth will have consolidated sufficiently to defy the water unless the bund is over-topped.

Of Engineering materials the Deraját possesses excellent lime, burnt from the limestone boulders found in the dry beds of the hill torrents. Good building stone is doubtless also procurable there, but the carriage is too expensive. Earth for bricks is plentiful enough but fuel is dear and bad. Wood is very scarce, two or three kinds of jungle timber are alone available in the district itself, but deodar and cheer are floated down the Indus or Jhelum from the Himalayas. Labor, both skilled and unskilled, is scarce; good workmen must be imported from the Punjab at high wages. There is a peculiar class of men, called *Odhes*, who migrate from place to place seeking work as beldars; they are excellent workmen, and very willing to take petty contracts; they are, I believe, emigrants from Hindustan. Carriage there is (or was) none available, except camels and a few pack bullocks or donkeys.

Years must probably elapse before the country of which I have been speaking can be rich or populous; but much progress has lately been made—old canals have been opened out, new ones dug, population has increased, the border is quiet, and in short the ordinary results of a few years of British rule are apparent. Much yet remains to be done however—in storing up the hill water—in guarding against the encroachments of the river—in still further improving the canals—and to the young Engineer, fond of his profession, it will for a long time remain one of the most interesting districts of the Punjab.

J. G. M.

No. CXVIII.

BRIDGE FOUNDATIONS IN SANDY RIVERS.

By R. G. Elwes, Esq., C.E., *Executive Engineer.*

It is proposed in the following paper to give some account of a discussion relating to the foundations of the Markunda Bridge, (near Umballa in the Punjab,) which has extended over several years, and will it is thought, be of general interest. It is hoped also, that the Madras Engineers may be induced to give the results of their experience upon the points raised.

A description of the Markunda river, with drawings of the bridge, as it is now being constructed, will be found in a former volume of these Papers (Vol. I., page 442).

The main point at issue is whether, in rivers with sandy beds of unknown depth and considerable slopes, it is on the whole preferable to carry down the foundations to such a depth that no danger need be feared from scour, (sufficient waterway of course being allowed,) without further protection; or, to make the foundations comparatively shallow, and to obviate the danger of scour by floorings or inverts, curtain walls, aprons of boulders or crib work, and similar means. For the sake of brevity the former plan will be spoken of as that of "deep," and the latter of "shallow" foundations.

The Markunda river rises in the Nahun or Sirmoor territory; it is subject to sudden and violent floods, which overflow the country for miles on either side. The bed is pure sand, or sand mixed with equally friable silt, to an unknown depth. Its declivity where it crosses the Grand Trunk Road is 2·72 feet per mile; and the highest *known* flood discharge, about 50,000 cubic feet per second, with a depth of 10 feet, and a velocity of about 5 feet per second. A more detailed description of the river is given in the paper above referred to.

The first design for bridging the Markunda river, of which I can find any account, appears to have been drawn up by Lieut. (now Major) Chesney, R.E., and submitted by Capt. Grindall, Executive Engineer of the Grand Trunk Road, in 1856. The design was for an arched bridge of brick, the arches 36 feet span, the foundations of piers and abutments resting on blocks 20 feet deep, and further secured by curtain walls of blocks above and below the bridge, which were also to be 20 feet deep. Between these curtain walls there was to be a continuous flooring. The foundations for one bay of the bridge upon this design were executed, and have been made use of in the present structure, as will be seen by referring to the plan at page 442, Vol. I.

It seems to have been expected that at a depth of 20 feet, a good stratum of clay would be found, but subsequent trials showed that the bed consisted of nothing but sand, and a mixture of sand and silt, to a depth of more than 40 feet. A few local patches of clay have been come across in the execution of the work, one of which probably misled those who made the original boring.*

In forwarding the design, Major Laughton, R.E., then Superintending Engineer, proposed to omit the curtains and flooring altogether, and to carry the foundations down to 40 feet. He objected to the curtains; first, because in order to be safe, they must be carried down to such a depth, that it would be cheaper and simpler to make the pier foundations themselves deep enough to be safe: and also, because the water would be likely to find its way between the blocks, wash out the sand, and so cause the floor to fall in. This prediction, it will be seen further on, has been exactly verified.

Colonel Hugh Fraser, R.E., then Chief Engineer of the Punjab, seems to have concurred in Major Laughton's views; but I have not been able to find his opinion on record.

Colonel W. E. Baker, R.E., then Secretary to the Goverment of India, however joined issue, and in a letter dated December 26th, 1856, to the address of Sir John Lawrence, K.C.B., he makes the following observations:—

" The value of curtain walls and the security of floors protected by them are well ascertained facts. To go no further, the Solani aqueduct is an instance in which both have been adopted, and have stood exceedingly heavy floods.*

"It is indeed precisely in great floods that these adjuncts to a bridge are so important. The irregular action of the current on the river bed at such times is the great difficulty with which Indian Engineers have to deal. It by no means follows that the action of the stream must always extend to such depths as 30 or 40 feet, but that where the protection of floors is not sought, circumstances which are then beyond the control of the Engineer may cause disturbances of the lower bed such as are spoken of.

"It will be a matter for consideration in each particular case, which is the best plan to follow; whether we should carry the depth of the foundations beyond the possible action of the floods, or whether we should protect the bed of the river in the vicinity of the piers by a floor and curtain walls."

Colonel Baker then proceeds to point out "the success which has attended the construction of the great dams or anicuts across the rivers of Southern India on foundations which rest on mere sand, and only go to a depth of 6 or 8 feet." He proceeds: "It is of course not to be understood that such small depths are suitable as a matter of course for bridge foundations in all rivers, but only that there are circumstances under which very moderate depths are sufficient, and that a careful consideration of every element is requisite before coming to any decision on such questions." To this letter were attached some extracts from Colonel Baird Smith's Work on Irrigation in Southern India, which it will be more convenient to give further on.

Shortly after Colonel Baker's letter was written, the mutiny broke out, and the Markunda bridge project remained in abeyance until 1859, when Mr. C. T. Campbell, C.E., who had been in charge of the Tonse bridge while in the service of the E. I. Railway Company, was appointed to re-examine the whole question. He submitted plans and estimates for four alternative designs, viz:—

1. Brick bridge, arches 80 feet span, on block foundations 40 feet deep.
2. Iron Wire Suspension bridge, on brick piers, one span of 500 feet, and two of 250 each.

* I believe the Solani curtains are blocks 20 feet deep, the intervals filled in with piles to the full depth. The importance of thus stopping up the intervals will appear presently.—R. G. E.

3. Cast-iron Girder bridge, spans 30 feet, on screw piles and cast-iron columns.
4. Iron Wire Suspension bridge, same as No. 2, but the piers formed of eight cast-iron columns, resting on cast-iron screwpiles, 2 feet in diameter.

In the elaborate and valuable report, dated January 1st, 1860, which accompanied these designs, Mr. Campbell strongly advocated the last, on the grounds of economy and minimum obstruction to waterway. In discussing the design for a brick bridge, he gives the following reasons for rejecting the flooring and curtain system. After observing that he proposes to omit these adjuncts, and to trust entirely to depth of foundations for the safety of the bridge, he proceeds :—

"Without for one moment questioning the well ascertained advantages attendant, in many cases, on the use of curtain walls and paved floorings, it may perhaps be doubted whether they would be so advantageous as blocks sunk to a depth beyond the action of the floods in such a torrent as the Markunda, rising so rapidly and tearing along with such force and violence. It must be remembered that it often brings down with it large trees, which, in an arched bridge, will be very apt to accumulate in one or more of the openings, obstructing them and causing the water to rush with redoubled force through the other arches. In such a case scour must ensue, and if it cannot have effect between the piers, it will cut above and below the curtain walls. Such instances I have seen occur before, on a small scale it is true, but still the rule will apply here too; and I have seen in a 15-feet culvert, founded on sandy soil, water, brought to a head by obstructions in the arch, force its way *under* a deep apron and *through* the joints of an invert, the mortar in which was well set. Had the invert been a flat paving it would probably have been blown up.

"Such an event might occur here, the water finding its way under and between the curtain blocks, blowing up and sweeping away the pavings; scour would ensue, and before anything could be done to stay it, the curtain blocks might be overturned, one or more piers undermined, and the whole bridge thrown down. This is of course an extreme view of the case, but it is precisely such views that must be taken into account in deciding a question of this nature."

Mr. Campbell's arguments, however, failed to convince the Government of India. Colonel Yule, R.E., then Secretary to that Government, in a letter dated May 20th, 1861, while acknowledging the care and labor bestowed upon the designs, preferred a modification of the original one to any of them. It was directed that the arches should be made from 37 to 40 feet span, so as to bring into use, if possible, the portion of work already executed. With regard to the foundations, Colonel Yule made the following remarks :—

" Well foundations may be used in two ways, viz., either by employing the wells as piles and sinking them till we reach a firm stratum; or where such a stratum lies very deep (as in the present case), by establishing a practically impermeable barrier under the bridge in the shape of flooring and curtain walls, to secure the foundations from scour. The last method has often been used on this side of India, (without, it is believed, a serious example of failure,) but it has never been so fully taken advantage of as in the Madras Presidency. There, as has before been precisely pointed out in correspondence on this very subject, well foundations of bridges, in sandy beds of unknown depth, are not sunk more than 9 or 10 feet, often less; the wells themselves being also of very rough and crude structure. Yet they stand safely; and it is mainly owing to the cheapness of this construction that so many noble bridges have been built in the Madras Presidency, over rivers such as we habitually leave unbridged, on account of the estimated cost. Indeed, the experience of Madras shows that well foundations of 6 feet in depth, on sandy river beds having a slope of 3½ feet per mile are secure.

" It is not necessary to go to such an extreme, in order to secure the advantages of a desirable economy. In revising the design, the depth of the pier foundations should be limited to 15 feet, and that of the curtains to 12. Round wells should be used instead of square blocks. They are more easily and rapidly sunk, and are just as good for the purpose now in question. But in the upper curtain wall the greater continuity of long rectangular blocks will be an advantage. The curtains should be kept well clear of the cut-waters of the piers."

Upon these instructions, the design given in Vol. I. of these papers, was prepared by Mr. W. Purdon, M. Inst. C.E., who had been appointed to the charge of the works. Round wells were used in the upper as well as in the lower curtain wall; in consequence of a difficulty in procuring wood suitable for block *neemchucks*. In the lower curtain, continuity was sought to be obtained by putting down two rows of wells, those in the second row being placed opposite the interstices of the first. The works were commenced in 1861, and up to the beginning of 1865, nothing occurred to throw doubt upon the security of the plan adopted, so far as the curtains were concerned.

In consequence, however, of the ease with which the pier wells were countersunk to the prescribed depth, it was thought desirable to sink them somewhat further, lest they should be unable to bear the weight resting upon them. It will be seen on referring to the drawings, that each pier rests on ten wells of 5 feet diameter, giving a wide base* independently of the concrete between the wells; but it was thought possible that the semifluid sand might yield lightly to the pressure, and so endanger the arches. The Government of India, in discussing the Excutive Engineer's proposal to sink the pier wells to 20 feet, observed as follows :—

"They (the pier wells) were, as settled by the Government of India, to be only 15 feet deep, instead of being sunk as usual in the N. W. Provinces, until they will descend no further. This small depth, when combined with a well protected flooring has been proved by Madras experience to be perfectly reliable, and it was considered an object to have an example on this side of India. Accordingly, the order was issued, and the wells have been got down to that depth; but with such ease, it is stated, that a further depth of 5 feet, considered 'wiser because safer,' has been ordered.

"Bearing in mind that works on wells only 6 feet deep, have succeeded in Madras in rivers with sandy beds, sloping 3½ feet per mile, a safe margin for the experiment was allowed, in ordering wells 15 feet deep in sand, the slope being certainly under 4 feet per mile.

"The Executive Engineer suggested this greater depth of 15 feet, because† he deemed that the river channel being contracted by the contemplated bund and the bridge piers, there may, in a flood, be a scour of from 5 to 8 feet of the silt deposited on, or rather forming the upper stratum of the bed. But if a scour takes place and foundations be endangered, the curtain wells will certainly be affected before the pier wells are. If the curtains go, the flooring also will go, and the pier foundations will then be exposed to an action they were never intended to, and certainly would not, withstand. * * * * * * *

* The pressure on each square foot of the wells supporting the piers, including the "hearting" of concrete is 3 tons.

† The chief reason seems to have been the doubt as to the bearing power of the wells in soft sand as noted above. The bund referred to has not been executed as yet, and will not contract the waterway.—R. G. E.

so that if 20 feet depth of well is necessary anywhere, it is in the curtain wells, which protect the remainder.

"It has not been overlooked that the depth of the curtain wells originally ordered, compared with that of the pier wells, is open to condemnation on the grounds now laid down, and it may with advantage be noted that in Madras, the bed of the river would in most cases, be protected to a greater distance below the bridge than 14 feet, whilst there is generally plenty of stone at hand for tail protection there."

By the time these orders reached the Executive Engineer, one row of curtain wells had, I believe, been sunk to 12 feet and filled in. They could not therefore be lowered; the greater part of the pier wells also had been sunk to 15 feet; and had stood for a rainy season. Upon recommencing work, it was found that they had become so earth bound that they could scarcely be moved; and thus, while the intention of sinking them to 20 feet was frustrated, the necessity for doing so was proved not to exist. Difficulty was found in getting even new wells down to 20 feet, and eventually the pier wells were left at various depths, according to the resistance experienced, from 15 to 20 feet.

It has been mentioned that only one row of curtain wells on the lower side were put in at first. From motives of economy, the second row was deferred, but unfortunately, the necessity of taking other precautions, such as piling between the wells, to make the single row a really impervious barrier, does not appear to have been sufficiently foreseen. The spaces between the wells were intended to be filled to a depth of 5 feet, with 3 feet of concrete, and 2 feet of masonry. From the high level of the water in the bed, or some other reason, it seems to have been impracticable to put this protection to its full depth at all points: in some places it was found to be only 3 feet, or even less.

The piers had all been built before the rains of 1864, and now the effect of the bridge in producing a scour of the bed might be expected to become visible. A gradual deepening of the channel had been taking place since 1859, when the zero of the gauge (the level of the flooring) was 2 feet below the lowest point in the bed of the river. In 1864, the lowest point of the bed was almost level with the zero, but in that year the highest flood was only 7·5 feet, the waterway was clear, and the state of the bed favorable. No scour was observed.

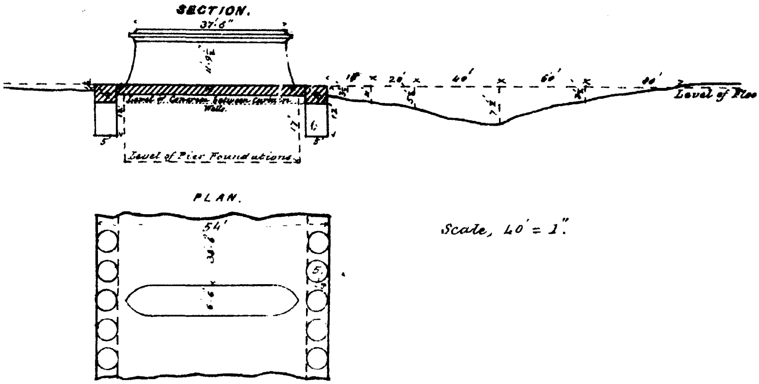
It must be remarked here, that the effects of a flood in the Markunda depend rather upon the suddenness with which the waters come down, and the state in which they find the bed, than upon the extreme height to which they rise. The channel is a wide shallow shifting bed, constantly getting choked by heaps of drift sand and banks of silt, which are sometimes thrown up to a height of 5 or 6 feet by a single flood, a corresponding encroachment taking place on some other part of the bank. The floods occasionally come down with extreme suddenness, so that people overtaken in the dry bed of the river are drowned before they can reach the bank. One flood had reached a height of 5 feet upon the flooring, which had previously been quite dry, in almost five minutes from the appearance of the first trickling stream.

In the spring of 1865, shortly after I took over charge from Mr. Purdon, who was removed to a higher appointment, a winter flood of about 4 feet came down, and being slightly obstructed by the masonry piers which supported the centerings on one side, and by large deposits of silt on the other, scooped out a hole about 4 feet deep (probably much deeper during the height of the flood) immediately below the curtain wall opposite two of the arches. Some sand was washed out between the curtain wells, which are 15 inches apart, and the connecting portion of concrete and masonry, which happened to be only 3 feet deep at this point, fell in. The edge of the flooring was taken up, but the injury did not appear to extend beyond the back of the curtain wells. The hole was filled up with concrete and masonry; and to protect the green work during the rains, a row of sheet piling was driven about 10 feet from the edge of the flooring in front of the two bays where the scour had occurred, secured by waling pieces to guide piles 12 feet deep. This protected the place for the time, but the accident set me thinking what would be the effect of a maximum flood of 10 feet in depth coming down suddenly, with the channel so blocked up with silt as it usually is. The section attached, taken 500 feet above the bridge, shows the state of the bed in February, 1866. The average depth of silt is 4¾ feet, and the area of waterway between the bed of the river, the abutments, and the springing line, 12 feet above the flooring, is only 9,041 superficial feet, which with the normal velocity of 5·5 feet per second, gives a discharge of 49,725 cubic feet. Now, a flood rising only to 10 feet above the flooring requires a discharge of very nearly 50,000 cubic feet. It was evident, therefore, that there must be a great heading up of the water at the bridge, until the river

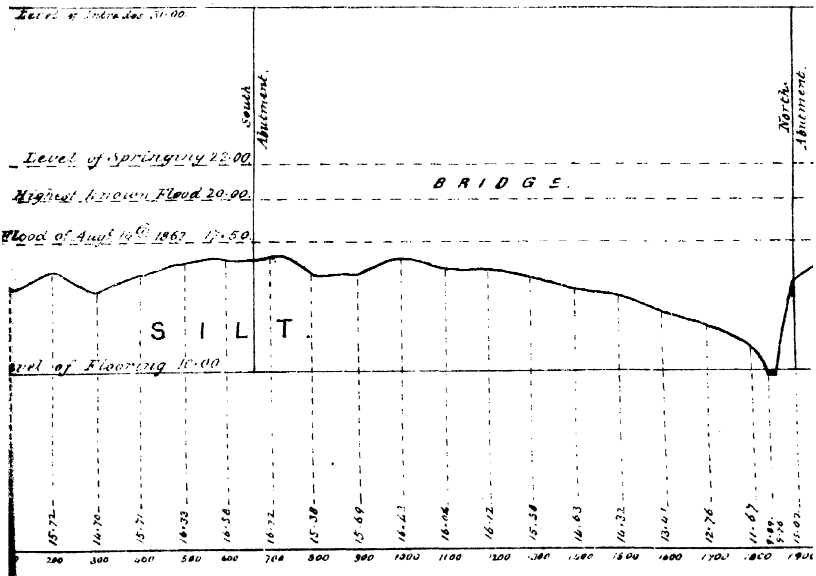
BRIDGE FOUNDATIONS IN SANDY RIVERS.

MARKUNDA BRIDGE.

Sketch, showing Scour produced by a Flood of 7·5 feet August 14th, 1865.—



Cross Section of Channel taken 500 feet above Bridge, Feb 26th 1866.



Scales
Vertical 10' = 1 inch.
Horizontal 200' = 1" „

could cut a passage for itself through the silt. If a slight heading up, probably not exceeding 3 inches of a 4-foot flood produced such unpleasant effects, what might not be expected from a 10-foot flood, with a fall, for a short time, of 2 feet through the bridge?

In the rains of 1865, the highest flood was about 7 feet on the flooring, and the effects left on its subsidence are shown in the annexed section. It will be seen that there was a scour of 1½ feet on the *upper* side of the flooring, and a hole scooped out on the lower side, 3½ feet deep at the edge of the floor, and 7 feet deep at a distance of 40 feet from the edge. This hole was gradually silted up as the water went down; it was measured when there were 3 feet of water on the floor; probably in the height of the flood the hole was much deeper. The scour was no doubt increased by the obstruction of the masonry supports for the centres, of which there were five in each arch, 3 feet thick and 4 feet high (less than the average depth of silt). But the obstruction of these was as nothing compared to that of the silt banks, which must be looked on as a normal feature, for though swept away more or less in the height of each flood, they are always reformed as the waters go down, and ready to dam up the first rush of the next flood.

It appeared to me, that had the foundations of the Markunda bridge been only 6 feet deep, this flood would have settled the question by carrying away the whole structure, and it became a matter of some interest to investigate the Madras data, which had made so much impression on the Government of India. About this time Major Crofton's Report on the Ganges Canal reached me, and I proceed to give some extracts bearing upon the point at issue. It is hardly necessary to remind readers that the slope of the Ganges canal, in the sandy parts, is only 15 inches per mile, that the depth is only 7 feet, the channel uniform and straight, free from drift, sand hills, or silt banks, and with a stream regular and constant, instead of a succession of *débacles*. Here is what Major Crofton says as to the state of the bridges:—

"Holes have been eroded in the bed below the Jowalapoor bridge, and all the falls, to the depths shown in the section. In one instance, at the upper Bahadoorabad Fall, the erosion extends considerably below the bottom level of the foundations. No injury, however, has resulted from this to any of the masonry works, *the talus of boulders and cribwork*, originally attached to each on the down-stream side, having transferred the excessive action of the current to a sufficient distance from the works themselves." Para. 4.

Again: "Very deep holes have been formed, as the longitudinal section will show, below all the masonry works in the sandy tracts; in some instances as at the Hafiznuggur falls and the Bailra bridge, extending several feet lower than the bottom of the foundations, but in no case has this affected the stability of the masonry works; *the talus of boulders or kunkur has everywhere proved its efficiency as a means of protection.*" Para. 13.

It is abundantly clear from Major Crofton's Report, that had the bridges on the Ganges Canal been protected by curtains only 6 feet deep (the foundations being of no greater depth) *without any talus*, many of them must have fallen in long ago. It is true that the velocity through these bridges is somewhat higher than that due to the original slope of the bed and the obstruction of the piers, alone, because the general erosion of the channel has converted the bridge floorings to some extent into sunk weirs. But the increase of velocity, due to this cause, cannot be great, for Major Crofton's states (para 29)—"that the heading up is very slight in every case; at some bridges it could hardly be detected by the levelling instrument." And whatever it may be, we have the same evil to contend against at the Markunda bridge, where the flooring is already about 6 inches above the level of the bed above and below bridge; an evil which will increase as the erosion of the channel goes on, until the slope of the bed has accomodated itself to the new regime of the river.

If then, as experience shows, very shallow foundations without a talus are unsafe in a stream with all the advantages of the Ganges Canal, they cannot be safe in a torrent like the Markunda, or those in Madras, with slopes of 3 or 4 feet in a mile. It is now time to examine the deductions drawn by Colonel Baird Smith from the works in Madras, which have evidently all along influenced the Government of India in prescribing the the mode of dealing with the Markunda. These deductions, quoted by Colonel Baker in the letter above referred to, will be found at pages 43, 44, of Colonel Smith's "Report on Irrigation in the Madras Provinces." I beg the reader's particular attention to the parts which I have italicised.

"*3rd.* That in rivers with beds of pure sand, and having slopes of 3½ feet per mile, such dams* may be constructed and maintained at a moderate expense.

"*4th.* That the *elevation of the beds* of the rivers above the dams to the *full height of the crowns* of these works is an inevitable consequence of their construction, and that no arrangements of under-sluices has as yet been effective to prevent this result.

"*6th.* That in pure sand, acted on by the current due to a fall in the river bed of 3½ feet per mile, and exposed further to the action of floods from 12 to 15 feet deep, well foundations in front and rear, of 6 feet in depth, have been proved, by an experience of 15 years, to be safe.

"*7th.* That with a vertical fall in rear of the dam from 5 to 7 feet in height, a thickness of 2 feet of brick masonry and 1 foot of cut stone, with a breadth of from 21 to 24 feet for the apron, have proved sufficient to insure stability, the only further protection required being *a mass of rough loose stones*, about 9 feet in width and 4 in depth. The loose stone apron should at first have a breadth equal to 1½ times, and a depth equal to two-thirds the height of the dam. The action at the tail of the work, *leading to constant additions to the loose stone*, soon deranges these proportions, and they are given only as guides in the first instance.†

"*8th.* That the *main security of the dam* depends upon the efficient construction and careful *maintenance* of the apron."

In the first place, these deductions apply solely to dams or anicuts, and Colonel Baird Smith makes no reference to bridges in this connection. What he does say about the Madras bridges when describing the Gunnarum aqueduct, will be quoted presently. Now the curtain and flooring system is open to two main dangers. First, that of the water finding its way between or under the curtain wells, and either blowing up the flooring or washing out the sand from under it. This is the objection urged by Major Laughton and by Mr. Campbell. Secondly, there is the danger of holes being scooped out by the scour below the bridge, which may extend back below the bottom of the curtain, and cause it to fall in. Of this I have quoted illustrations from the Ganges Canal.

The first danger can hardly occur to an anicut; the action of the dam

* That is, dams (anicuts) similar to these in Tanjore, for distributing the waters of a river, at the head of its delta, among its several branches.—R. G. E.

† Perhaps some Madras officers will kindly state the size and description of stone used for these aprons, and the extent to which they require renewal every year.—R. G. E.

raises the bed of the river to a level with the crown of the work, so that the water must find its way down 7 + 6 = 13 feet to get under the upper curtain, which is further protected by an up-stream apron. The solid body of the dam itself, and the strong apron of masonry 3 feet thick, are sufficient to protect the work from being blown up or undermined. The danger of scour below is provided against by the talus of loose stones, which has to be continually watched and renewed. This talus Colonel Baird Smith declares in the case of the anicuts, as Major Crofton in the case of the Canal bridges, to be the main security of the work. It is the omission of this essential protection which appears to me to render the design laid down for the Markunda and other large bridges so insecure. The talus or apron alone, however is not sufficient, unless the curtains be made really impervious, so that there is no danger of the flooring being undermined. For this purpose it would be better to use blocks, instead of wells, both up and down-stream, and to fill up the spaces beween the blocks with accurately fitted piles.

I have not been able to find any description of a bridge in Madras, built over a river with a sandy bed on a slope of 3 or 4 feet to the mile, upon shallow foundations, even with the protection of a stone apron. The Gunnarum aqueduct, which is sometimes quoted as an example, is not a case in point. Colonel Baird Smith gives a description of this aqueduct.* He does not mention the slope of the branch of the Godavery river over which the work is constructed; but I gather from his report that the average slope of the high floods of the main river is from 15 inches to 18 inches per mile; also that the general slope of the country longitudinally is about 12 inches per mile. Probably the slope of the bed under the aqueduct does not exceed the latter amount, and it appears from Major Crofton's Report on the Ganges Canal, para. 131, that the stream is a tidal one, the tides rising and falling 3 or 4 feet at the site of the aqueduct—where there is consequently a considerable break-water on the flooring. The aqueduct consists of 49 arches of 40 feet span; the springing line is 11½ feet above the flooring. The piers rest on wells 8 feet deep: the curtain wells up and down-stream are 4 feet deep. Above and below the curtains are aprons of loose stone, the upper one 5 feet, the lower one 16 feet, wide. The depth of these is not given. The soil is described as "sandy."

* (Irrigation in Madras, pages 111, 118.)

Colonel Baird Smith evidently entertained grave doubts of the wisdom of pushing economy to such an extreme, independently of the objections to the contracted waterway of this aqueduct. He says: "It seems to be possible to secure foundations on the rivers of Southern India, *with their very low slopes*, by means which, with our own experience of the rivers of Northern India, we should be justified in pronouncing utterly inadequate, and with which in fact we should never dream of operating, since *they would inevitably fail on the first serious trial*." It is evident that Colonel Baird Smith, never intended to apply the results of the Madras *anicuts*, to the case of *bridges* in Upper India, where the conditions are so different.

The conclusions to be drawn from the facts above described were sufficiently obvious. First, that far too much stress had been laid on the success of shallow foundations in Madras, and that the plan had been applied under circumstances and conditions quite different from those of the anicuts which had furnished the idea; Secondly, that the main and most essential element of the Madras system, the talus or apron, had been entirely omitted; Thirdly, that the foundations of the bridge could not in their existing form be relied on, and that some further protection was necessary.

Several remedial measures suggested themselves; the first being to sink the second row of curtain wells opposite the interstices of the first, as originally intended. This was soon given up, for the following reasons:— As the flooring had been put down, the sinking of a second row of wells so close to the edge would inevitably draw out the sand from under it, and thus give rise to the very evil it was desired to remedy. Moreover, it appeared that the greatest scour occurred opposite the ends of the cutwaters or starlings, being caused by the "swirl" or eddy of the water meeting below the piers. The edge of the flooring was so close to the cutwaters, that the additional width of 6 feet aided by another row of wells would give no protection against this action, and it seemed desirable to extend the flooring further down stream. Lastly, it was considered that a curtain wall in such a stream, unprotected by any apron, and exposed to a scour such as had already begun to show itself, could not be safely made less than 20 feet deep. To sink wells 3 or 4 feet deeper than those on which the piers rest, at a distance of only 7 feet clear from the end well of the pier, was not to be thought of.

Cribwork, filled with brick or slag, would be as expensive as masonry and less efficient.* No boulders were available for a loose apron, and for the above reasons it was recommended that the flooring should be extended 40 feet down-stream, by an apron of concrete 2 feet thick, terminated by a row of blocks 12 × 6 feet, sunk to a depth of 20 feet, with intervals carefully filled up by piling to within 5 feet of the top, which space was to be occupied by a continuous platform of masonry. It was also recommended that the curved wing walls which had been given in the original design but afterwards omitted, should be restored on the up-stream side of the bridge, as there was a considerable tendency to cutting along the face of the abutment on either bank. The cost of the proposed additions was estimated at Rs. 1,03,782.

In a report, dated 31st December, 1865, which accompanied a revised estimate for the bridge, including the protective works described above, I gave the following summary of the question of foundations :—

" If, as appears from the experience of the Ganges canal, very shallow curtains *without a talus* are not safe in a sandy bed with a fall of only 15 inches per mile, and a depth of 7 to 8 feet, *à fortiori*, they cannot be safe in a torrent like the Markunda, or those in Madras, with slopes of 3 to 4 feet in the mile, and floods of 10 to 15 feet in depth. If, indeed, the curtain be protected by an apron of boulders or cribwork, carefully watched and continually repaired, as seems to be the practice in Madras, the system would, no doubt, be safe; and in situations where suitable materials can be obtained cheaply, it might be more economical than the alternative of very deep wells with no flooring at all. But the Markunda Bridge, as observed by the Government of India, is neither one thing nor the other. *Without* a talus (which owing to the scarcity of wood and stone would be nearly, or quite, as expensive as the deep curtain wall now proposed) the bridge cannot, in the face of the facts above quoted, be considered safe; *with* either of these additions it will have cost more than if built on wells 40 feet deep without a flooring, as originally proposed by Mr. Campbell."

No decision has been come to at present upon the measures to be

* I doubt it. I think the loose brick, which is free to fall down and fill up the sand as it is undermined or sucked away, would be far preferable to the solid masonry flooring proposed, and which would certainly crack when undermined from irregular settlement. The brick slag should be in large masses to prevent its being swept away, and a rough timber grating over it might perhaps be advisable for the same purpose.—[ED.]

adopted; but I hope at a future time to complete this paper by giving the subsequent proceedings in the case, and the results of the remedies which may be applied to the evils that have shown themselves.

Postscript.—Since the greater part of this paper was written, several pieces of the flooring have fallen in, having been undermined by the sand being washed out between the curtain wells. In one spot at least there appears to have been a regular stream flowing through *under* the flooring, from the upper to the lower side of the bridge. The anticipations expressed by Major Laughton in 1856, by Mr. Campbell in 1860, and by myself in 1865, have been fulfilled.

R. G. E.

Memorandum by the Superintending Engineer.

I have not been long enough in this circle of Superintendence to have acquired much personal knowledge of the conditions of the Markunda river, and the experience of one comparatively scanty rainy season cannot be considered as full data.

But however applicable the system of shallow foundations, with protective pavements and curtains, may have proved in the Madras Presidency, there has not been as yet, that I have seen, any record to show that General Cotton has considered this system to be applicable to bridges over rivers of great slope, in very light or sandy soils; and which, in Northern India, are further subject to sudden and violent floods, causing a velocity much in excess of the velocity as calculated from the slopes of the beds.

It is further clear that the liability to cutting under the bays of a bridge is much greater than in the case of dams and weirs, so that the latter cannot be accepted as a guide to the former.

The system of shallow foundations was introduced into the N. W. Provinces about sixteen years ago; and I was, I believe, one of the first to take up the idea in its experimental application to bridges. These experiments were limited to drain bridges of two or three arches, each under 20 feet span, including some long and low viaducts with arches of 10 or 15 feet span, with the prescribed protective pavements and curtains, and always with the addition of enrockments or tail pieces below bridge, in cases of much velocity. The conclusion to which these cases have led me is that the system of shallow foundations, with its adjuncts, will generally be sufficient for drain bridges in moderately firm soil, without much slope, supposing the whole to be under periodical supervision.

But the same experience, combined with later inspections of large bridges in sand or sandy soil within the N. W. Provinces and the Punjab, has convinced me that there must generally be true economy in such cases, by sinking the foundations proper, *i. e.*, those under the piers, abutments, and even wing walls, as far as they can be driven without extraordinary exertions, and under no other limit, short of 40 feet, which will in almost all cases be deep enough to be beyond the action of the water, with sufficient lateral pressure on the wells or blocks, to support the bridge. The value of this support will of course be greater in proportion to the advisability of dividing the total weight over many lines of support, but in this consideration the question of economy, as well as of waterway, will enter largely.

Under any circumstances, the foundations should evidently go deeper than the possible action of the water.

Pavements, with curtains of more or less depth, are always useful in cases of considerable velocity to equalize the action of the stream through the bays of a bridge, and I have always found enrockments or tailpieces to be much more valuable than seems to be generally supposed. They prevent serious injury during the floods of one season, and if partially displaced, they serve as a warning to adopt further measures.

But curtain walls cannot be used in all situations. Such curtains imply a stoppage of the water below the river bed, and it follows that any undercurrent filtering through sand, must be forced either above or below the curtain. The former would be inconvenient as raising the head of water, and the latter would be fatal both to pavements and curtains.

Against the system of shallow foundations, with their adjuncts, in sandy soil, is the clear fact that the least derangement, causing a movement in such soil, must upset all previous calculations, and there is no saying when sand, once in movement, may stop.

A large bridge is I believe the last kind of structure to be considered in the most economical point of view, so far as the foundations under piers and abutments are concerned. Further, the cost of pavements, curtains, and tail pieces, with their after repairs, will I think seldom leave much in favor of shallow foundations, as compared with deep foundations in the first instance, which do not require all these adjuncts.

The case of the large Markunda bridge may be considered as a bold experiment, made with the special object of placing beyond doubt if possible, the economy of shallow foundations in the Punjab; but present appearances are not in favor of the theory, although the sinking of some of the pavements is doubtless partly due to the mode of construction, as carried out from motives of economy. There have also been strong symptoms of a tendency to extensive cutting below bridge, which has necessitated the proposed addition of a broad tail piece of masonry, failing the presence of stone within any reasonable distance, and this cutting is of course quite independent of the mode in which the pavements and curtains have been built, while it would always threaten shallow curtains, however well built, if allowed to go on. The foundations proper have not yet been affected, and the expense to be now incurred for further protective measures, may be fairly calculated against the expenditure saved in the first instance, by avoiding deep foundations, and in the economical construction of the pavements and curtains.

It may be remarked of the system of shallow foundations that they cannot be expected to last long, without constant or periodical repairs to the protective works.* Such protective works connected with works of irrigation in the Madras Presidency probably *pay* while they last, which is doubtless a sound calculation (so far as the Public Works Department is concerned), when capital is not immediately available for extensive works on a more permanent basis: but it seems equally evident that works of a permanent nature would *pay better*, supposing capital to be available. Expenditure on original works is generally a more prominent matter, and more apt to catch general attention than a succession of expenditure on repairs, and we have to consider that in many parts ot Northern India, the means of periodical repairs are comparatively expensive from the scarcity of wood and stone.

The quotations made by the Executive Engineer from the opinions given by several Engineer Officers, and from the orders issued by Govern-

* And probably, constant attention to the state of the river bed, so that accumulations of silt formed during the rains, and causing an irregular current through the bays, should be regularly cleared away in the cold weather.—[ED.]

* With the omission of a row of wells.

No. CXIX.

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

(4TH ARTICLE.)

Compiled from the Annual Reports of MAJOR-GENERAL SIR ANDREW WAUGH, R.E., F.R.S., *late Surveyor General of India.* BY H. DUHAN, ESQ., *Personal Assistant to Surveyor General.*

THE next party to be reported on is the *Madras Topographical Survey* party, under Captain Saxton. Although the tract inhabited by the Gonds and other aboriginal tribes, extending from near the Coromandel coast to the Nagpore territories, is not of much value to the revenues of the British Government, and is peculiarly difficult to survey on account of the physical features of the country, as well as its insalubrious character, still a general survey of the whole tract on a moderate scale appeared an important requisite for political and military purposes, and the general objects of Government; accordingly arrangements were made for a scientific survey of Ungool and the surrounding country, work being commenced at the extremity of the South Parasnath Series near Balasore, which enabled Captain Saxton to commence with data furnished by the G. T. Survey, thereby securing accuracy and saving much time and trouble in measuring base lines and determining a point of departure.

Captain Saxton reported that the whole country was jungle, but the ranges appeared favorable for triangulation, which the party proceeded to lay out in advance. A little after the middle of December, sickness commenced; and shortly afterwards, increased to an alarming extent. Captain Saxton, and two of his assistants, were compelled to proceed to Cuttack for medical aid, and the whole party was in fact disorganized; the season's operations proving thus nearly a failure.

Notwithstanding the anxiety which these untoward circumstances occasioned, the Surveyor General felt reluctant to declare the undertaking impracticable. The unhealthiness of the climate in all December being clearly demonstrated, orders were issued that the party should not reach their ground before 1st January. On the other hand, the climate becomes dangerous by the middle of March. The season being thus limited, it was a great object to strengthen the party as much as possible, which having been done, the results of the next two seasons were more satisfactory. The hill tract under survey was reported as being covered with dense and unwholesome forests, hardly animated at long and distant intervals by a sparse population of aboriginal tribes in the lowest stage of barbarism. The area surveyed was 2,515 square miles, of which 565 were on the one inch, the remainder on the half-inch scale.

In 1849, immediately after the conclusion of the Punjab war, a survey of the neighbourhood of Peshawur was commenced at the desire of the Military authorities by Lieuts. Garnett and Walker, Engineers, which was gradually extended so as to include a *Military Survey of the Northern Frontier Trans-Indus*, the operations being placed under the control of the Surveyor General. 400 square miles were completed by June 1849, when Lieut. Garnett was sent to Kohat, and the work was continued by Lieut. Walker* alone. That Officer adopted a scale of an inch to the mile, except in the vicinity of the city of Peshawur, where the work was taken upon the 2 inch scale. The instrumental equipment was unfortunately of a small kind, as instruments of the highest power could not have been employed or carried in such a disturbed country.

Operations had been commenced by measuring a base line of 2½ miles in length, and triangulating therefrom. The sides of the triangles varied in length from 4 to 16 miles, their general average being 6 miles. By December 1849, Lieut. Walker had completed the survey of the

* Now Lieut.-Col. Walker, R.E., Superintendent G. T. Survey, and Officiating Surveyor General.

ground south of the Caubul river, and east of the city as far as Naoshera. He was then directed to accompany the field force proceeding to Eusoofzai, during which time the survey was of necessity discontinued.

Immediately after the close of the military operations, a survey was ordered of the valley of Loondkhwar in Eusoofzai. Having no time to carry up the triangulation from Naoshera, a new base was measured, and a survey made of 150 square miles, on the scale of 2 inches to the mile. This being effected, Lieut. Walker triangulated backwards to his former network, and found a difference of 2 yards per mile in the common side of junction. This is a degree of error to which minor triangulation depending on bases measured with common chains at different seasons, carried on with small theodolites reading to minutes, and with indifferently marked signals, seems to be fully liable, and which can only be avoided by the rigorous precautions of the G. T. Survey system. About the middle of May, Lieut. Walker returned to cantonments for the recess, during which a map was made of all the country that had been surveyed, and a copy forwarded to the Board of Administration at Lahore.

Ill-health prevented his returning into the district before the end of November, about which time he recommenced operations from the vicinity of his base line in Loondkhwar, proceeding east to the Indus, thence south to Attock and finally west, until a junction was again formed with the former triangulation terminating at Naoshera. To test the accuracy of these operations he measured a third base near the banks of the Indus, and found a discrepancy of a yard per mile. The work was improved by the grant of additional establishment, enabling the stations to be marked by pillars, but the telescopic power of the theodolite was so feeble, that opaque signals were seen with great difficulty, and the accuracy attainable was thereby greatly limited.

The area surveyed up to the end of season 1850-51 was reckoned about 3,100 square miles, of which nearly 2,000 belong to the British Government, and the remaining 1,100 to independent Pathans. This last portion, though hostile, was surveyed with nearly as much accuracy as the former, and on the same scale. The cost was about Rs. 3¼ per square mile. By September 1851, a map was completed of the whole valley of Peshawur, including Eusoofzai, and as much as Lieut. Walker could get access to, or see distinctly, to the north and west beyond the frontier.

His adventures while surveying among hostile tribes were of a most interesting description, and often attended with great risk. He had frequently to obtain access to his stations, by causing diversions to draw off attention for a limited time, during which he had to take his observations and then ride hard for life. By tact and management, as well as cultivating friendly relations with the Chiefs, he succeeded in conducting his work without collisions, and with only a single accident, on which occasion his native groom was killed.

Having been supplied with more powerful instruments, the survey was continued during the following season, being first connected by a series of triangles with the Base at Attock, so as to form part of the G. T. Survey. Lieutenant Walker's Khattak Hill Series orginates from the side, Attok to Pir Subak, of the G. T. Survey, and was skilfully conducted to Kohat. Owing to the dangerous character of the Afridi tribes, his scope of selection was limited. For the same reason the connection of Kohat and Peshawur, though only 30 miles apart, was of necessity dependent on a series of triangles nearly 150 miles in circuit. These deviations from a direct course were unavoidable, and are mentioned only as illustrating the peculiar difficulties of the survey.

During the season 1852-53, Lieut. Walker completed the survey of the whole highland frontier Trans-Indus, embracing the Southern Khattaks and Bunnoo, besides extending a reconnoissance into the plains of the Deraját, as far as Dera Ishmael Khan. In the progress of his operations, he took many observations for fixing the chief visible points of the ranges beyond our boundary. Fourteen peaks were thus determined, extending over a distance of 50 miles along the summit of Safed Koh, or the White Mountains, which constitute the watershed between the Cabool and Koorum rivers. Thus, and with the assistance of native information, he made a tolerable map of the country beyond our boundary, as far west as 69½ of longitude.

The total area of British territory thus brought under survey, exceeds 6,000 square miles; and the survey has been of the highest utility in the subsequent numerous military operations against the frontier tribes.

In the season of 1853-54, the Surveyor General measured the Base

Line near Attok in the plains of Chuch. Subsequently, the Base Line apparatus was carefully transported to Karachi, where in the season following, the Karachi Base Line was measured. These two Base Lines complete the linear verifications required for the great quadrilateral figure of Sironj, Dehra, Attok and Karachi. The results of the verification of the important series of triangles terminated by these bases are given below; and considering the extent of the triangulation they must be considered satisfactory.

Error of North-west Himalaya Series at Chuch Base line, (the value by triangulation being in excess,) 1·262 feet or 0·30 inches per mile.

Error of Great Longitudinal Series at the Karachi Base line, (the value by triangulation being in defect,) 1·165 feet or 0·17 inches per mile.

During the previous year, Major (then Lieut.) Tennant, R.E., had been directed to build an observatory on a favorable site selected for the purpose near Karachi, in order to verify by celestial observations the value of Latitude and Azimuth brought down from Sironj by the Great Longitudinal Series. One of the great Astronomical Circles employed on the Great Arc was used for this purpose. The results were as follows:—

		Latitude.		
At Karachi observatory,	by celestial observation,	94°	49′	49″·273
„	by Great Longitudinal Series,	94	49	50″·155
	Discrepancy,	0	0	0″·882
		Azimuth.		
At Karachi observatory,	by celestial observation,	179°	59′	57″·425
„	by Great Longitudinal Series,	179	59	57″·737
	Discrepancy,	0	0	0·″312

This officer also successfully carried out a series of Tide Observations with a self-registering gauge, for the purpose of determining the datum at Karachi for the survey heights.

During 1858, arrangements were made for carrying up a special series of *Levelling Operations* from the tide gauge at Karachi to the Chuch Base, for the purpose of determining accurately the height above the sea level of stations in the interior, and furnishing a precise datum for the mountain operations. Hitherto the heights determined by the G. T. Survey of India have been deduced entirely by means of reciprocal vertical angles, except in the case of short levelled lines necessary to connect the tide gauges with the nearest stations of the triangulation. Since the improvements introduced in the process of Trigonometrical levelling, the results have proved highly satisfactory, especially in hilly tracts, where, from the nature of the circumstances, spirit levelling is inadmissible, and the Trigonometrical process by reciprocal verticals can be practised under great advantages. In the plains, however, the case is reversed, and on account of the uncertainties of terrestrial refraction in rays grazing so near the surface, great anxiety was felt lest error should accumulate in such long lines of operations, as the survey had to deal with in the plains of Northern Hindostan. The very accurate results obtained by the Trigonometrical levelling have already been remarked, (see page 104,) but they nevertheless appeared to the Surveyor General not sufficiently in keeping with the wonderful precision attainable in all the other results of the survey. Much depends on an accurate determination of the height of the base lines, in regard to their reduction to the sea level, which affects the lengths of the arcs and all the linear distances of the Survey. It was also a matter of great interest to bring up an accurate datum from the sea to the Himalayas, in connection with the determination of the heights of those stupendous peaks. It was further a matter of importance to furnish an accurate datum to the Canal Departments of Sind, Punjab and the N. W. Provinces; and to connect their levelling results, and those of the Railway Department, with our own. For all these reasons, it was determined to carry a line of levels up the valley of the Indus with the greatest precision attainable, and with all due attention to the extraordinary refinements usually practised in Trigonometrical operations, though not hitherto attempted in ordinary levelling. The great distance to be levelled, and absence of the means of verification at the termination, rendered unusual precautions indispensable.

The first part of the Indus Series crosses a hilly tract, and a similar highland region occurs before the triangulation terminates at the Chuch Base, a distance of 960 miles. With these exceptions, for the greater part of its course the series traverses, by the aid of towers, a flat alluvial plain. The party under Major Walker was equipped with

THE GREAT TRIGONOMETRICAL SURVEY.

Towers erected for the principal Triangulation in the Plains.

Fig. 2.

Transverse Section.

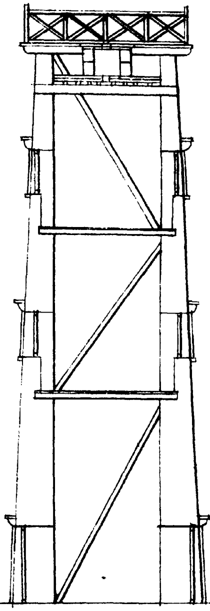


Fig. 1.

Elevation.

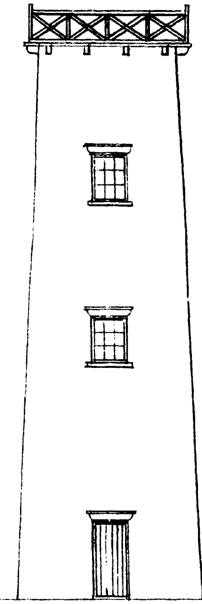


Fig. 3.

Ground Plan.

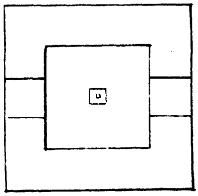


Fig. 4.

Plan of 1st Story.

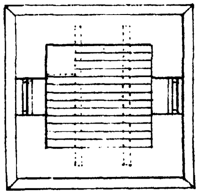
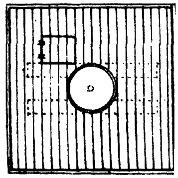
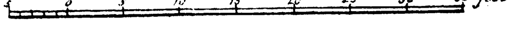


Fig. 5.

Plan of Platform.



Scale 25 feet = 1 inch.



three first-class standard levels by Troughton and Simms, transferred for this purpose by the Punjab Canal Department. These had powers averaging 42, and a focal length of 21 inches. Graduated scales were attached, so that the level errors could be recorded and corrected for, in the same way as in Astronomical observations. It is humanly speaking impossible to level an instrument practically without some residual errors, however small, but it is practicable to note the errors and compute the corrections due to them, a process by which accumulation of small errors is prevented. The staves were made for the special purpose in the Mathematical Instrument Department, graduated on both faces in a peculiar manner, and with every precaution as to conformity with the unit of measure of the Indian Survey. For the subsequent verification of the unit, a standard bar was supplied as a provision against accident or change in the staves.

As a precaution against the intrusion of gross errors and to lessen the anxiety which a single leveller must experience if he works alone for months, without knowing whether his results are accurate or not, it was determined that three observers should level along the same pins one after the other, using each his own instrument and staves. Thus, any error could at once be detected and rectified on the spot, and the work was thus subjected to check at each step of its progress.

The operations commenced at Sojra tower, and the levelling was carried upwards in a continuous rise. After proceeding some distance a personal error was discovered of a very minute but constant character, whereby the results of the three observers diverged from each other. Though the differences were extremely small, their constant character gave reason for anxiety in regard to their accumulating tendency on a long line of 960 miles. This led to a long discussion, which ended in the adoption of an alternating system of observation, whereby the benefits of a circuit system were obtained, and many sources of instrumental error counterbalanced. By these means, the differences between observers were much reduced, and in some cases counteracted. The work beginning at early morning at the lowest temperature and maximum amount of aqueous vapour, it was evident that as the temperature rose the air became drier, and the refraction constantly diminished. Though the difference taking place in the interval between a back and forward sight, was extremely small, and its effect almost insensible on the third place of decimals of a foot, still the tendency being constant, its accumulative effect might be dreaded on so long a line. For these reasons the staves were observed, and the observations repeated in an alternate manner at each station, as also at alternate stations. Similar precautions against the accumulation of minute quantities were taken in the manipulation of the instruments. In order also to introduce the highest degree of refinement the work was susceptible of, new levels, freely mounted and supported at the two points of least flexure, and covered with glass cases, as a protection from currents of air, were prepared in the Mathematical Instrument Workshops.

In the course of these levelling operations, numerous bench-marks were buried at important places, seven canal and railway bench-marks were connected and nearly 200 mile-stones marked. The connection with the Canal and Railway affords a check by circuit. For example, Major Walker's levels from Shikarpore to Kotree *viâ* Larkhana and Schwan, with the Canal levels *viâ* Sakkar and Hydrabad, close with a discrepancy of only 0·09 foot in 560 miles.

The result obtained from this series of levelling operations is most satisfactory, and indeed, may be pronounced a triumphant feat; as will be seen from the following statement, viz :—

1.	From Karachi sea level to Chuch Baso (Spirit levelling), ..	960	miles.
2.	N. West Himalaya Series, (Chuch to Banog,) Trigonometrical mountain levelling, ...	412·8	"
3.	Great Arc Series, from Banog to Sironj, ...	445·0	"
4.	Great Longitudinal Series, Sironj to Karachi sea level, ...	678·4	"
	Total length of circuit,	2496·2	"

This circuit of levelling, chiefly Trigonometrical, and embracing 210 miles of Trigonometrical levelling over plains, closes with a discrepancy of 0·753 of a foot, giving a rate of only $\frac{3}{10000}$ of a foot per mile.

On the Great Indus Series there were two independent levelling operations, viz. : —1st, The Trigonometrical levelling along the series which is 710 miles in length, of which 384 are unfavorable plain country; and, 2nd, Spirit levelling over a circuitous route of 960 miles. The comparisons between the two results at the points of connection along the series are highly satisfactory, and the ultimate results most gratifying, as will be seen from the following statement:—

	Feet.
Height of west end Chuch Base, by Spirit levelling, brought up from the sea level at Karachi, ...	1014·603
Height of same point brought up by Trigonometrical levelling, from same datum, ...	1012·30
Difference between Spirit and Trigonometrical levelling,	2·303

This gives a rate of error on 700 miles of ·003 of a foot per mile, which is wonderfully accurate for Trigonometrical levelling, especially over a tract of 384 miles of unfavorable country.

The next series to be reported on is the *Kashmir Series.* After the completion of the Karachi Base, Captain Montgomerie R.E., was deputed on this duty, and commenced Trigonometrical operations on the Kashmir meridian. The first season's triangulation having been laid out across two ridges of the snowy mountains, and advanced into the heart of Kashmir, the Surveyor General proceeded to organize arrangements for the Topographical Survey, which was to be based on this triangulation. On account of the small establishment at disposal, the difficulty of obtaining Uncovenanted Assistants, owing to the competition of other departments of the State, the length of time consumed in training new hands, and the difficulty of retaining them when trained, application was made for three or four young Officers of the Quarter-Master General's Department, to survey during the summer. Three officers, viz., Captains P. Lumsden, C. C. Johnson, and G. Allgood were accordingly temporarily transferred. Lieut. Elliott Brownlow of Engineers, with two assistants from other parties, were also allotted to the mountain survey. By this means the Trigonometrical establishment was strengthened sufficiently to advance the Great Series towards Thibet, and at the same time cover the area to be surveyed with points of reference for the topographical operations.

The system of survey adopted was that described in the Topographical instructions for the Department. The advantage of this system in a country like India, especially in the hilly and mountainous tracts is, that officers with a moderate previous knowledge of military drawing can readily be trained to fill up the triangles; and the work proceeds rapidly, producing a complete and valuable map, with the topographical features accurately delineated at small expense.

The three Assistants Quarter-Master General being wholly untrained to the rigorous system of surveying required, had first to be instructed; but were after a moderate probation able to proceed independently, and by the end of the season had accomplished a fair share of excellent work. For the ensuing season of 1857, it was fully expected that these three officers would have been again available. Unfortunately the exigencies of the service did not admit of this, and their previous season's training was thus lost to the survey.

The arrangements made for the prosecution of the Topographical survey having thus broken down, the whole business of training and instruction had to be recommenced *de novo*. Three other officers with the requisite qualifications were selected, viz., Captain H. H. Godwin-Austen, H. M.'s 24th Foot, Lieut. A. B. Melville, 67th N. I., and Ensign W. G. Murray, 24th N. I. These officers speedily learned their duty, and did excellent service. The strength of the Kashmir party was also increased by Lieut. Basevi of Engineers, and Assistants from other parties being transferred for the summer season.

Neither the physical character of the country, nor the constant task of training new hands formed the chief difficulty of the survey conducted in a foreign territory, and which at no time could be expected to be agreeable to the Ruler, his officials, and people. To them the influx of a considerable body of surveyors, spread over the country, however orderly and well conducted, must bear the aspect of intrusion. Captain Montgomerie had some difficulty in maintaining amicable relations with the Court, and his difficulties were enhanced by the Military Rebellion of 1857, during the whole of which excited period the party continued its peaceful and useful labors without cessation, and with only one serious interruption.

The character of a Trigonometrical survey demands that the stations shall be fixed on the highest summits, or on points commanding extensive views, and it is requisite that an adequate number of good observations shall be taken, which usually occupies several days. To accomplish this task, not only the observers, but the signal men (natives), must encamp at or near the stations. The heights of some of the peaks ascended on the Punjab range were Moolee station, 14,952 feet; and Ahertatopa station, 13,042 feet; and to the north of Kashmir, Haramook, 16,015 feet. Among the highest elevations visited in Thibet were the principal stations of Shimshak and Shunika, 18,417 and 18,224 feet, respectively. The difficulty of obtaining supplies and fire-wood at such elevations may be imagined, yet they were every day occurrences. Out of sixteen principal stations in Thibet, fourteen exceeded 15,000 feet in height.

Although the splendid climate of Kashmir, added to the special interest attaching to the country and the unexplored tracts adjoining, made the survey deservedly a great attraction, still the exposure of surveying in such a country is very trying to the constitution, and many persons suffered greatly. The lower valleys are very hot, and the solar radiation on the hill sides is very powerful. The labor of climbing to great elevations has often been noticed by explorers; the surveyor, however, arriving heated by physical exertion at great elevations, has to stand on ridges or peaks, exposed to strong cold winds, while he is observing angles or sketching the ground.

The whole mountain tract south of Kashmir proper was completely triangulated and topographically surveyed. In 1859, the triangulation was satisfactorily advanced in Thibet, but the Topographical operations made slower progress than usual, owing to the smallness of the establishment the Surveyor General was able to devote to that work. The work effected may be briefly summarized as follows:—

1st. Area triangulated from commencement of survey to 1859, about 50,000 square miles, (nearly equal to the area of England,) five years.

2nd. Area topographically surveyed in four years, about 23,000 square miles.

3rd. Cost per square mile, Rs. 4-5-2.

These results are highly satisfactory in quantity, quality, and cost.

The Coast Series is a most important work, as it connects the metropolis of India with the Madras Observatory, which is the origin in Longitude of the Survey of India. This operation also defines the coast. Unfortunately, however, the triangulation traverses a country presenting formidable difficulties, among which, the baneful climate may be reckoned the worst. The work was commenced at the Calcutta Base by the late Captain Thorold Hill, who was succeeded by Mr. Clarkson and Mr. Peyton. The obstructions presented by the climate and other difficulties were so great that the progress had been slow, and the cost correspondingly high. The parties had been annually decimated by sickness and driven thereby from the field. But the work was nevertheless, with singular constancy and perseverance, gallantly resumed, season by season, until by slow degrees it nearly reached Cuttack.

The Rahoon Meridional Series commenced in 1852, was necessarily suspended during the two following seasons, owing to the party being employed at the measurement of the two Base Lines. Work was shortly after resumed, and the series progressed satisfactorily. The party after the conclusion of the season's work in 1857, on returning to recess quarters, passed through Delhi and Meerut only a few days before the out-break of the mutiny, thus narrowly escaping destruction. In 1857-58, the country south-west of Delhi, through which the series passed, was so disturbed that operations could not with any regard to safety be resumed. Next year the country still being unsettled, the party was transferred to the Gurhagurh meridian, under Major Tennant.

The Gurhagurh Series was undertaken to lay down Ferozepore, and furnish fixed points for the incorporation of the Revenue Survey with the general map of the Punjab. The season proved unfavorable, and but little final work was done; but good progress was made in 1859-60 by Mr. Shelverton, who succeeded to the charge of the series, on Major Tennant's appointment to be Astronomer at Madras. Lieut. Herschel of Engineers, was appointed to fill Major Tennant's vacancy.

Mr. Nicholson's health having succumbed to the baneful climate of Assam, Mr. Lane was deputed to succeed him in the charge of the *Assam Series*. He pushed forward the work with great energy, accomplishing an excellent season's progress; but the mutiny having broken out, his party was in some danger from roving bands of mutineers, chiefly of the 34th Native Infantry. In the seasons subsequent to 1857, the progress of this work diminished, owing to the difficult and unhealthy character of the country, and its destructive climate.

The next Trigonometrical operations to be reported on, are those conducted in the Bombay Presidency. *The Bombay Trigonometrical Party*, under Captain D. G. Nasmyth, R.E., had been employed south of the Great Longitudinal Series in triangulating Goojerat, Katyawar, and Cutch, and connecting the operations with Sind. Crossing the

Runn of Cutch and the little desert, the nature of the country presented obstacles of the most formidable character, as well in regard to provisions, water and travelling requisites, as in finding suitable sites for towers, and the materials for their construction. The observations also from atmospheric vapour and mirage, were rendered peculiarly difficult and harrassing. The whole tract of country embraced by Katyawar and Cutch was fully triangulated and prepared for Topographical Survey. The numerous series into which this triangulation is divided, close most satisfactorily, showing extreme accuracy of observation, beyond what could have been expected from an 18-inch and 12-inch instrument.

Captain Nasmyth proceeded to England on furlough and was succeeded by Lieut. Haig, R.E., who was employed in the ensuing season in completing the Gogo Series, and forming a connection between the Aboo and Singi Meridional Series.

It is now necessary to summarize the proceedings of the various *Topographical* parties. Of these, the Kashmir Series has already been reported on in connection with the Trigonometrical operations under Captain Montgomerie.

Captain D. G. Robinson's survey of Jhelam and Rawul Pindee is second to none in importance, or in the excellence of its results, and the interest attaching to the locality. This great work was commenced by Captain Robinson at the close of the year 1851, and the field work was brought to a successful conclusion early in 1859. The area comprised in this survey amounts to 10,554 square miles, so that the rate of progress has been 1,319 square miles per season. The progress would have been more rapid but for several retarding causes. The cost of the eight field seasons amounts to Rs. 1,93,465-15-10, which, divided by the area, gives Rs. 18-15-2 per square mile, for the rate of the field-work.

The scene of this survey is of great interest and importance in a classical, military, geological and engineering point of view. The locality is rendered memorable as the scene of Alexander the Great's exploits, and as embracing the line of operations by which India has been invaded from the time of Alexander to that of Nadir Shah and Ahmud Shah Abdalli. It abounds in strong positions, and an elaborate and accurate map of this part of the country is therefore of great importance in a strategic point of view. To the geologist it is of importance as containing the saliferous strata of the Salt range, and various formations of great interest and curiosity. In an engineering point of view, the utility of an accurate survey is manifest, and Captain Robinson's results have proved useful in facilitating the operations of the Great Road.

After the measurement of the Chuch Base, Mr. Mulheran an experienced surveyor of the department, assisted by Mr. Johnson, was deputed to finish a small portion of the great snowy range, lying between the heads of the Baspa and Ganges rivers, including the Nela Pass, which had not been travelled by Europeans or natives for many years, owing to the danger attending the crossing of the lofty and difficult part of the range. The Nela station is 19,086 feet high, and on account of its southern aspect and consequently greater depth of snow, the ascent is a more difficult achievement than an ascent to a similar altitude on the north side of the Himalaya. Mr. Johnson surveyed all the difficult ground at the head of the Baspa and Nela pass, as well as from Nilang to the Jala Kanta pass; while Mr. Mulheran finished the difficult ground at the head of the Charang, Nisang and Rishi Dogri, in Bissahir, east of the Sutlej, and continuous with Chinese Tartary. After this feat, the party was transferred under Captain Montgomerie to Kashmir, and Mr. Mulheran proceeded to organize the *Hydrabad Topographical Survey.* Mr. Mulheran's superintendence of this Survey proved successful, and justifies the expectation that the remaining portion of this survey, which embraces no less than 95,000 square miles of country, or an area larger than Great Britain will be finished in a moderate time.

In the year 1858, the Deputy Surveyor General applied for Trigonometrical points on which to base the Nagpore Revenue Survey. The Great Trigonometrical Survey not having been extended over that part of the country, Mr. Mulheran was deputed to carry a branch Series from the Great Arc to Nagpore.

(To be continued.)

THE GANGES CANAL COMMITTEE.*

In a former number of these papers, an attempt was made to give a brief and impartial account of the Ganges Canal controversy. As this has since passed through several new phases, it will probably be interesting to our readers to show what has since been done, and what new data of professional interest have been elicited.

In January 1864, a Committee of Engineer Officers, composed as under,† and comprising the ablest Irrigation authorities in Upper India, was convened at Agra, and a Memorandum drawn up which set forth briefly as follows:—That it was admitted by every one that the Ganges Canal was originally designed with too great a declivity of bed, and that in consequence of this mistake, considerable erosion of the earthen channel had taken place, and many of the masonry works were in danger of being undermined and destroyed—That without extensive alterations, the present canal could not safely carry the full supply of water which it had been originally designed to pass, and that the carrying out of such alterations would probably render necessary a temporary closure of the canal to the serious detriment of the irrigation interests of these provinces—That the amount of water which the present channel, if *unaltered*, could safely carry, being inadequate to the wants of the country, the rest of the available supply might *perhaps* be carried by a supplementary channel from Roorkee through another part of the country, and which should rejoin the original channel lower down—That an officer of experience (Captain Crofton, R.E.) should

* Report of the Ganges Canal Committee. Roorkee, 1866.

† Col. Strachey, R.E., Secretary to Government, P. W. D.; Col. Morton, R.E., Chief Engineer, N. W. P.; Col. Turnbull, R.E., Superintendent General of Irrigation, N. W. P.; Capt. Dyas, R.E., Superintendent General of Irrigation, Punjab; and Capt. Crofton, R.E., Superintendent Eastern Jumna Canals.

be appointed to report on the whole subject, and especially on two alternative schemes above sketched.

In November of the same year, Captain Crofton submitted Report, and a perusal of it will amply justify his Chief's encomi of "the energetic and able manner in which he has in so shor time accomplished a most arduous task." This report gives 1st, complete account of the present state of the canal; 2nd, Recomme dations for remodelling the present line so as to enable it to car the full supply with safety; 3rd, A project for the alternative supplementary line; 4th, A design for a separate *navigable* line (apa from irrigation); 5th, A comparison of projects and cost; 6th, reply to Sir Arthur Cotton's objection to the general design of th canal. The general conclusions to be drawn from the whole Repor are—That the preferable alternative is to remodel the present line both on the score of efficiency and economy; and that Sir Arthu Cotton's proposals were altogether impracticable.

The principal measures recommended for remodelling the existing line were briefly as follows:—1. Reduction of the slope of the bed (by the construction of additional falls), and increase to the sectional area of the channel, with an additional opening to the bridges. 2. Alteration of existing Ogee Falls into Vertical Falls with gratings. 3. Raising bridges where the headway is insufficient. Of these measures it is obvious that the first was by far the most important and expensive, and that the third has reference to navigation requirements only. The total estimated cost of these alterations was Rs. 39,19,850, or including compensation for temporary closure and loss of revenue, Rs. 52,68,063, which would finally raise the total cost of the canal to 2½ millions sterling.

Examining this Report somewhat more in detail, the following facts are elicited. As to the present state of the canal: the violent action of the water has chiefly shown itself in scouring large holes below the Bridges and Falls, but the former, protected by the *talus* of boulders and crib-work, are perfectly safe—the latter, where the falling water has of course added greatly to the dangerous action, have not been materially injured, except at one or two works, where inferior masonry had been used—here the floorings were torn up and the foundations endangered.* This action was further increased (and the canal banks also much cut away below) by the inward curve given to the water-walls on each bank. In the case of the Bailra Falls, where the material was no better, the water-walls, being curved *outwards*, formed a large basin, in which the velocity of the water shot down the ogee fall is destroyed, and thus a greater depth of back-water secured on the flooring; here the injury done was trifling. The difficulty of executing the necessary repairs to these works has simply been in the fact of the water having to be turned on (when the canal was re-opened) before the masonry had had time to dry. There seems no reason to doubt, that first rate brick masonry is both hard and strong enough to resist the most violent action of the water, when there is no defect in the original design.

From a variety of observations, given in detail, in an interesting Appendix to the Report, the safe maximum velocities for the remodelled channel have been taken as 2·5 feet per second for the worst soil, such as sand hills; at 2·7 feet for sandy soil generally; and at 3 feet per second for the ordinary soil met with (a light clay).

This Report, it may be observed (as well as the Memorandum by the Committee of Engineers in which it was based), was drawn out without any direct reference to Sir Arthur Cotton's views; which are, therefore, only incidentally replied to among the "Concluding Remarks," and to the most important of that Officer's objections, involving in fact, as Captain Crofton says, *the* main point at issue, little more than two pages are devoted in reply. Indeed, the real gist of the reply is contained in a marginal note subsequently added; and we cannot but think it was a mistake not to have entered more fully into the important question raised; if necessary, by a separate Appendix; or else to have left it alone altogether, as foreign to the subject matter of the Report.

* At Mahmoodpore, in the left chamber, the floor, whose least thickness was 6 feet, was quite cut through, and a hole 15 feet deep eroded in the sandy substratum. At Jaoloe, the brick-on-edge covering to the floor was in places bulged upwards, as if blown up from below, and water was seen to spout through the side walls 3 or 4 feet above the flooring.

Sir Arthur Cotton's point was, as will be seen by turning to the former article, that the canal had been taken off at too high a point on the river's course, thereby having to run the gauntlet of the whole of the upper drainage of the Doab, whereas it should have been taken off at some lower point near Sookertal, below the junction of the drainage lines with the river. To this Captain Crofton replied, that the river bank at this latter point was too high and that the excavation of the Canal would have required a cutting of an average depth of 53 feet on a direct course of 57 miles, so that the earthwork alone would have cost more than $2\frac{1}{2}$ millions sterling. But, as Sir A. Cotton had already said, that no such direct course would have been chosen, but a circuitous route under the high bank until the ground suited for piercing it at a small cost, Captain Crofton added a marginal note in reply, explaining that such a course would be impracticable on account of the difficulty of dealing with the drainage from above, and the necessity of carrying the canal for many miles in high embankment above the valley, which, for so great a body of water, could not be considered safe. Doubtless to Engineers acquainted with the locality such a course would be considered clearly out of the question, and if Sir Arthur Cotton had himself inspected it, he would probably have thought so too, but to those not on the spot his views merited, we think, at least a more careful and detailed reply than they received in this marginal note.

The Government apparently thought so too; for soon after the publication of Captain Crofton's Report, and on Sir Arthur Cotton's re-iterated assertions that his views had not been properly considered, it was resolved to appoint a Committee of experienced and impartial Engineers* to report on the whole question, and decide whether Captain Crofton's proposals should be accepted or whether further action should be stayed, "pending the preparation of a detailed project according to the views of Sir Arthur Crofton."

The only exception that can be taken to this course is, that as Sir

* Col. Lawford, Madras Engineers, *President;* Lieut.-Col. Anderson, Madras Engineers, Lieut.-Col. Fife. Bombay Engineers, Geo. Sibley, Esq., Chief Engineer, E. I. Railway, H. Leonard, Esq., C. E., *Members.*

Arthur Cotton had never gone beyond an expression of views and suggestions, it would perhaps have been better to call upon him for a detailed project, to be prepared by himself, or some Officer nominated by him, and supported by plans and estimates, and *then* to have laid the two projects side by side before the Committee. As it is, the Committee have necessarily had to base their Report on Estimates which they have had to draw up for themselves,* and which necessarily are only approximate, and on data which were for the most part furnished by one side only. On the other hand, the preparation of such a detailed project must have involved considerable delay, and it was highly desirable that some definite decision should be come to without further loss of time.

The Report of this Committee has just been presented, and a more able and impartial document it would be difficult to find. A very careful examination was made of the whole country affected by the questions at issue, and the opinions arrived at show that those questions have been carefully considered under every possible phase, as well as that more immediately presented for solution. The conclusions finally come to by the Committee may best be stated in their own words:—

"I. That the construction of a weir across the Ganges below the confluence of the Solani, with other necessary works for supplying water to the canal, at an estimated cost of Rs. 1,12,86,314, cannot be recommended.

"II. That the project for opening an additional canal head, including the construction of a weir on the Ganges at Rajghat, or other point in that part of the river, at a cost of Rs. 1,13,04,170, for bringing under irrigation lands not now watered by the canal is feasible, but should be held in abeyance until the probable returns appear more proportionate to the outlay than at present.

"III. That the construction of a weir across the Jumna at Toghlukabad, with a canal for the irrigation of that part of the Doab below Allyghur, not under the influence of the Ganges canal, at a probable cost of Rs. 35,45,701, inclusive of branch channels, is practicable, and that the project should be further

* Sir Arthur Cotton has, indeed, already protested, in anticipation, against the Committee's Report, partly on this very ground; but his objections to its constitution, on the ground that no Officer representing his own peculiar views was upon it, seem unfair. The Committee were to sit as judges not as advocates, and the Government rightly replied, that he had the opportunity of stating his own case through Col. Rundall, who was known to hold the same views, and who had been invited by the Committee to accompany them in their inspection and assist them with his suggestions.

investigated; but they are of opinion that it cannot be substituted for any portion of Major Crofton's project.

"IV. That Major Crofton's project for remodelling the Ganges canal should be proceeded with, subject to the modifications suggested in this Report.

"V. That the construction of a permanent weir across the Ganges at Hurdwar, though not indispensable while the present reduced quantity of water is passed down the canal, will become a matter of absolute necessity in order to maintain without risk of interruption the full supply of 7,000 cubic feet per second."

These conclusions are stated at the commencement of the Report, and the facts on which they are based are set forth in detail afterwards. An interesting account is first given of the physical peculiarities of the Gangetic Doab, which Sir P. Cautley and the Bengal Engineers have always maintained had a great deal to do with the argument at issue, but which Sir A. Cotton has always denied. These peculiarities, as distinguishing a Doab from a Delta, have already been described in the former article, and the only additional fact here elicited, seems to be that referring to the difference in the nature of the sandy beds of the Ganges and such rivers as the Godavery; the latter of which is described as a large coarse-grained sand, more nearly resembling gravel; while the Ganges bed consists of a fine powdery sand, which is much more liable to be acted upon by the current of the river. This is an important point as affecting the depth to which it would be necessary to sink the foundations of any weirs thrown across the Ganges, which the Committee think should be 15 feet deep (in lieu of the 6 feet wells that have been found sufficient in Madras rivers), even when protected, like them, by a long talus of stones on the down-stream side.

With regard to a weir at Sookertal, much stress is naturally laid on the distance of any adequate supply of material to form both the weir itself and the protective talus. The cut stone required would cost at least Rs. 2 per cubic foot. Blocks of concrete made from the shingle on the spot are recommended as the cheapest material that can be used for the principal part of the work, and they are estimated to cost about the same as brickwork, Rs. 20 per 100 cubic foot. The whole estimate for the weir itself amounts to 44 lakhs.

The most favorable course for the supply channel is then carefully indicated. It would run for 29 miles along the Khadir, or low land, being partly in cutting and partly in heavy embankment, and would then run through the high ground for 23 miles in heavy cutting; after which the excavation would be moderate as far as the junction with the present line. The total cost of the channel is estimated at 68¾ lakhs.

The entire cost, therefore, of such a head to the canal would be 112¾ lakhs of rupees; and as the headworks and channel, as executed by Sir P. Cautley have cost only 81 lakhs, it is evident that the balance of cost is greatly in favor of the scheme actually carried out. Moreover, the first sum is only an *estimate*, and from the difficulties of the work, as explained by the Committee, it would not unlikely be greatly exceeded in actual practice.

The possibility of a weir lower down at Rajghat is then canvassed, the only essential difference between this and the higher site being, that block kunkur is available for the work at a distance of some 14 miles.

At Toglukabad, however, on the Jumna, a little below Delhi, a weir is considered practicable, mainly on account of the proximity of abundance of stone; but it is so low down that such a site could merely be looked upon as a feeder for the lower branches of the canal, and would not at all take the place of works required for the supply higher up. Mr. Sibley so far dissents that he would, however, look upon this as *the* source of supply for the lower portion of the canal, leaving the upper portion to carry its present (short) supply without any alteration. But the rest of the Committee dissent from this view, and Mr. Sibley only states his opinion with the proviso that the quantity of water available from the Jumna in the dry season shall be found to approximate to 3,000 cubic feet per second, an amount which does not appear likely to be realized.

As to the present condition of the canal, the Committee entirely concur in the view taken all along by the Canal Officers, that its one fault is in the too great declivity of the bed; but they remark with surprise, that after all the fault found with it, "it has been carrying nearly two-thirds of its full supply for the past 20 months, and that the navigation, though imperfect, has been going on without interruption for the same period, during which the canal has not been closed for even a single day," while "the area of irrigation has steadily increased year by year." * They then proceed to criticise Captain Crofton's project for the remodelling, and while generally agreeing in the measures proposed, and deprecating any false economy in such an important matter, suggest a reconsideration of some of the details, as involving changes which seem unnecessarily expensive.

The Committee think that it would be possible to execute that portion of the new works below the water-line in two short closures of 3½ months each, by which the loss of revenue would be slight, but Mr. Sibley dissents from this opinion, and the time certainly seems very short, especially when the difficulty of laying the foundations dry in the first instance is duly considered.

The importance of a permanent Weir for the canal head at Hurdwar in then alluded to; though, as is acknowledged, the subject has for some time engaged the attention of the local Canal Officers.

With regard to the Hurdwar stone, of which so much has been said, the Committee "are satisfied that although stone of good quality may be obtained in small quantities, scattered over the hills, yet there is apparently no single spot where quarries can be opened with the prospect of an abundant supply being met with." Further search, however, is recommended in the main range of the Himalayahs, but it is evident that even with water carriage from Hurdwar, the cost of working and expense of land carriage from the quarries will raise it to a very high rate per cubic foot, far exceeding the most expensive brickwork.

A very interesting Memorandum is appended on the Financial State of the Canal, showing that even in its present undeveloped state, the net proceeds for the past Financial year have returned 3½ per cent. on the total cost; or, if the approximate estimate of increase to Land Revenue be added, not less than 5 per cent. At the same time, attention is drawn to the fact that the original object of Government in sanctioning this work was not so much to form

* The total receipts for 1865-66 are Rs. 13,39,047.

a source of revenue from the price paid for water, as to have a guarantee against the recurrence of famine and failure of the land revenue, while the general improvement of the country was looked to to repay the outlay indirectly. Hence the low water-rates charged, the returns from which have alone been credited to the canal; while the Committee quite concur with Col. Dyas, that the enhancement of the land revenue should be as clearly shown on the profit side of the account. Calculations are then gone into to show, that as soon as the full supply can be passed down, and the system of irrigation fairly developed, so that the water may do the same amount of work which it does steadily on the Jumna Canals, the net returns will not only suffice to pay 5 per cent. on the total cost, "but to pay off the accumulated interest of former years; and that once effected, to yield a clear profit of 8 per cent. per annum, *exclusive* of the enhancement of land revenue." "Considering therefore all the circumstances noticed above, which have hitherto tended so materially to frustate the success of the Ganges Canal in a financial point of view, the Committee are of opinion that its comparative failure up to the present time, affords no ground for doubt of a fair and reasonable return from other irrigation projects, constructed with the express object of yielding a direct profit." Such an opinion, formed carefully from actual data, by a Committee of impartial men, cannot but be considered as in the highest degree satisfactory and encouraging in regard to future schemes, which have doubtless been suspended while the Ganges Canal has been as it were on its trial.

Some remarks are made in explanation of the difference of Financial results in the case of Madras and Bengal irrigation works, and as this is a subject that has been greatly misunderstood, we have though it best to give Col. Anderson's note on the subject at full length, in another part of this number.

The Committee rightly lay stress on the importance of a system being devised as soon as possible for distributing the canal water by measurement, and not charging for it by the area irrigated. They point out that the present method tends to extravagance in the *consumption of water, and hence of course to loss of revenue. The late Col. Baird Smith, it is well known, was strongly in favor of such a system being adopted, thinking rightly that on a new work like the Ganges canal, where no previous system had to be overturned, it* was advisable to persevere in introducing a more scientific system, even at the risk of the irrigation being more slowly developed.

This principle has, however, we believe, since been abandoned; the old system of area measurement found more favor with the people; and, undoubtedly, since the contract system has been generally abandoned, the annual revenue has increased very rapidly. There is too, of course, the practical difficulty that no satisfactory pattern of water module has yet been devised, which shall be economical and efficient, and not likely to get out of order. But it is difficult to conceive, that if a liberal reward were offered, mechanical skill would not be found sufficient to overcome the difficulty, and we cannot but think that, meanwhile, the roughest approximation to accuracy would have been preferable to the present system which wastes water, involves the keeping up of large establishments, and entails enormous labor on Canal Officers,* even if it does not open the door to peculation more than the other.

We must now leave this very interesting Report, trusting that Government will extensively circulate it amongst Irrigation Officers; and though it is to be feared that some extreme partisans may not be satisfied with the opinions set forth, we believe that the verdict so carefully given, will be accepted by the profession and the general public, as a satisfactory settlement of the points in controversy.

J. G. M.

* There is no more reason why a Canal Engineer's time and professional experience should be employed in questions of Revenue and disputes about water, than that the Engineers of a Railway, when once made, should be employed in looking after the traffic.

No. CXX.

IRON BRIDGE OVER THE GOOMTEE—LUCKNOW.

THIS graceful structure, of which an Engraving is given in the Frontispiece of the present number, consists of three cast-iron arches supported on piers and abutments of brick masonry, the centre arch having a span of 90 and a rise of 7 feet, while the two side arches have spans of 80 feet, and a rise of 6 feet. The iron work was received from England in 1798, during the reign of Nawab Saadut Ali Khan, only twenty years after the erection of the first iron bridge in England, General Martin, who was then living at Lucknow, having it is supposed suggested the idea to the Nawab.

The bridge was designed by Rennie, being very similar to one erected by that famous Engineer over the Witham, at Boston, in Lincolnshire. The iron work remained unused at Lucknow *more than forty years*, when the bridge was at length erected by Col. Fraser, Bengal Engineers, between the years 1841-44; the cost of the masonry and erection having been Rs. 1,80,000; the cost of the iron work is not known.

The foundations are sunk on wells in the usual way. The width of roadway is 30 feet, and its height above watermark at the centre is 35 feet.

W. D. B.

No. CXXI.

THE HASTINGS' SHOAL.

Report upon the Hastings' Shoal in the Rangoon river. BY HUGH LEONARD, ESQ., M.I.C.E., F.G.S., *Superintending Engineer.*

THE impediment on which a report is required being a local one, confined to a single spot in the Rangoon river, and directly affected by local causes only, it does not seem necessary to write a long or general description of the rivers by which it is formed; it will be sufficient, and most likely better adapted to the end in view, to consider only such facts as bear directly, either upon the formation of the impediment, or upon the work considered necessary for its removal. Neither does it seem necessary nor even desirable, to enter upon any lengthened consideration of the value to the port of the removal of the impediment; indeed, considering the rapidly increasing importance of Rangoon, it would be difficult to estimate it. The officers of the Local Government are the best judges of this part of the question, and no doubt it will be carefully considered by them. The report will therefore, be confined to facts bearing directly on the best and most economical means of removing the impediment, and of keeping the channel clear when opened.

The town of Rangoon is situated about 30 miles from the Gulf of Martaban, on the most eastern offshoot of the Irrawaddy river. This offshoot is the fine navigable channel known as the "Rangoon river." A mile or two below the town, the river is joined by a branch known as the "Pegu river,"—a channel about as large as the Rangoon. Through the land situated between these two rivers, a third flows, joining them at the very

point where they meet; this is known as the "Pussondoon creek;" it is very small when compared with either of those which it joins. Just above this point of triple junction in the Rangoon river, the "Hastings' Shoal" is situated. (See plan).

From the Gulf of Martaban to the Hastings' Shoal, there is a very fine navigable channel, varying from a mile to half a mile in width, with ample water at every stage of the tide for any class of vessel. Immediately below the Hastings there is five fathoms, a little further up it shallows to one and a half, then to one, and this state of shoal water is carried,—measuring along the track which ships usually take,—for about a mile. The shoal is nearly the same height from bank to bank, having from 6 to 7 feet in it at low water springs. It varies much in length; near the left bank, it is not more than one-third of a mile long; in mid-channel it is more than a mile; and on the right bank, it commences at a point about a mile above the Pegu river, and extends for several miles down-stream, joining on to the "Liffey Sand." The rise of tide at Rangoon is about 20 feet in springs, and about 12 in neaps; so that generally, even at neaps, most ships can get over at high water; while during springs, any vessel trading to Eastern ports can cross. The inconvenience caused by the shoal is *delay* in entering the port; it does not shut any vessel completely out. The current during spring-tides is sometimes as much as four and a half knots an hour; during neaps it is not more than two knots. There are strong freshes down the Rangoon river, so strong as to prevent ships from swinging to the floods; but on the Pegu river, ships always swing.

The shoal seems to be formed of fine sand covered over in places with a thin coating of mud. The following are the data from which this conclusion is drawn. The surface of a sand, which is a continuation of the of the Hastings, was carefully examined at low water. An iron rod was run down in the tail of the shoal to a depth of 15 feet below low water. The Captain of the Steam Tug *Vulcan*—who is said to know more about the "Hastings" than any one in Burmah—states, that he has known a channel 18 feet below low water to have been scoured out after a heavy fresh. Such data are tolerably convincing, quite enough so for the present purposes of this report; but if works are to be carried out, a much more careful examination must be made before commencing them. The nature of the examination necessary will be described further on.

There are undoubtedly, ample grounds for concluding that the cause of the formation of the shoal is the action of the water of the Pegu on that of the Rangoon; both theory and experience point very decidedly to this conclusion. The Pussendoon creek has some slight influence on the action of the two rivers; but it is so slight, it may be neglected in the examination of the question. A river carries silt on account of the force of its current being strong enough to move particles of matter either in suspension or rolling along the bed, a certain strength of current moving matter up to a certain size. If the velocity of the current be diminished some of this matter will drop or stop moving, and where it stops, a shoal will be formed. There are many movements in rivers by which the velocity of the current may be diminished ; one is, that if two streams, moving in different directions, strike against each other, the velocity of one, or of both, must be diminished,—the laws governing them being the same, within certain limits, as those governing other bodies in motion under similar conditions. The greater the angle between the two streams, the greater the disturbance and check caused by their junction. Now, in the case under consideration, the Pegu rushes into the Rangoon ; they strike each other at a very bad angle, consequently, a great disturbance and a diminution of velocity in one or both must follow. The Pegu passes a greater volume of water than the Rangoon; the current of the latter gives way, the velocity is diminished, silt is dropped, and the Hastings' Shoal is formed. This is the theoretical view of the case. The practical view is, that it is a well known fact that wherever two rivers meet at a bad angle, if either, or both, be silt bearers, there is always a shoal above the point of junction in one, if not in both; the size and position of the shoal depending on the relative size of the rivers, the silt which they carry, and the angle which they form near the point of junction. For instance, the Roopnarain river falls into the Hooghly, which it meets at about right angles; it is a larger river than that into which it falls; both carry a large quantity of silt, the result is a very bad shoal in the Hooghly above the point of junction. Again higher up, the Damoodah also falls into the Hooghly; but the Damoodah is the smaller of the two, and they form a much smaller angle at the point of junction than that formed by the Roopnarain and the Hooghly; the result is a shoal above the point of junction: but it does not extend across the river, and causes little inconvenience compared with that formed by the Roopnarain. The Pegu and the Rangoon act very much like the Roopnarain and the Hooghly; the result in one case is the " Hastings' Shoal," in the other the James and Mary Sands. In addition to the fact that the Pegu passes more water than is passed by the Rangoon, there are two reasons why the shoal should be in the latter river. First, the Rangoon carries much more silt than the Pegu; consequently it contains one of the elements necessary for the formation of shoals to a much greater extent, and hence the shoal is more likely to be formed in it. Next, the Rangoon widens just above the point where the Pegu joins it. The Pegu does not widen at the junction, so that the water of the Rangoon has more room to spread; spreading tends to slacken the current, and consequently to form the shoal. It is not at all improbable that the widening of the Rangoon may be the *result* of the shoal, and not its original cause: but, be that as it may, the effect of the widening now, is to keep up the shoal.

If the only point for consideration in designing works for the improvement of the river were, how to form a channel through the shoal as it now stands, it is quite certain that the simplest and the cheapest way of doing the work would be to *dredge*—the undertaking would be neither difficult nor gigantic. But it is extremely probable that if a channel were dredged out, the agency which formed the shoal would fill it up again, and that too, very rapidly. It is known (information received from the Captain of the *Vulcan*, already referred to) that a channel has been formed—scoured out by a heavy fresh in the river, once at least—and that it filled up again as soon as the dry season set in: now, if this channel, formed by the action of the current, filled up so quickly, it seems reasonable to conclude that an artificial one, however made, would not remain longer open. The quantity of silt carried by the river even now—the month of February—is very large, it would be difficult to ascertain at what rate it would deposit in a channel while being dredged or when finished; but there seems to be every reason to fear, that it would deposit faster than a very powerful dredger could take it out. A machine costing about two lakhs of rupees would take fully two years to dredge a channel 600 feet wide, 3,000 feet long, and 15 feet deep,—as small a channel as it would be desirable to confine a project to,—and this it appears would silt up in one year; if so, it would take two such dredgers to keep the channel deep, even after its formation. There seems to be but one condition under which a resort to dredging, without other works in connexion with it, could be recommended. It is this; Captain Williams, who was Executive Engineer of Rangoon for some years, and who understands thoroughly the requirements of the place, states, that it is of great importance that a large quantity of low-land along the river edge should be raised, and he thinks, that the best, if not the only means of getting materials to raise it, is by dredging in the river. Captain Oliphant, the Chief Engineer, is understood to be of the same opinion. Now, if this view be correct, and that it be considered worth while to employ a steam dredger to get materials to raise the ground, then decidedly one should be purchased and set to work to dredge a channel through the part of the shoal which would be most likely to remain open. In this way, it might be settled whether it is possible to dredge a channel, and to keep it deepened or not; the question would be practically tested in a very satisfactory manner, without any unprofitable outlay. If it *be* decided to dredge, the following particulars will be of use. The best line to follow in dredging a channel, is marked on the plan:—A good dredger should put the material into barges, at a cost of about one rupee per 100 cubic feet; every expenditure, save the cost of plant, included. The best class of dredger for such work is a "double dredger," with ladders at the sides, protected by framing; engines 20 horse-power, nominal; self-acting gear to move vessel fore and aft, and transversely; ladders to work in 30 feet of water. The best place to have her built is in the Clyde. The cost in Moulmain should be about two lakhs of rupees.

But, for the deepening of the shoal, and the permanent maintenance of a channel through it, apart from such considerations as have been discussed above, the main works must be designed with a view to the removal of the *cause* of the impediment. If the reason already given for the formation of the shoal be correct, the aim of any work designed for its removal must be to prevent the Pegu waters from entering the Rangoon at such an angle as they now do—cutting them off altogether being an impracticability. Although rivers injure each other so much when they unite so abruptly, they would do comparatively little harm if they joined when forming a very sharp angle, that is when running in nearly the same direction. The effect of such an arrangement can be well understood by observing the movements of bodies afloat on rivers. If two vessels moving at right angles to each other were allowed to strike when moving rapidly, without altering their courses, the result would be great injury to one or both: but if they were made to curve round as they approached, and were only allowed to touch when they had taken the same, or nearly the same course, little if any inconvenience would be felt. So it is with bodies of water if they strike when running at right angles to each other, great disturbance, loss of velocity, and the formation of a shoal is the result; but if one or both be trained round by banks or other works until they run nearly parallel to each other, they may join and run together without any great disturbance of either. The blue arrows on the plan show how the Pegu runs into the Rangoon now,—it drives the Rangoon water right across the channel, completely changing its course and regimen; the red arrows show how it *should* enter in order to fulfil the conditions just explained. If the two rivers can be made to take the courses shown by the red arrows, they will have little, if any, further tendency to damage each other; and the nearer they can be brought to this course, the less will be the injury arising from their junction. In addition to directing the course of the currents by the works at Pussendoon creek, two alterations are desirable,—to narrow the Rangoon river at the shoal, by bringing out the right bank so as to keep the water from weakening its scouring power by speading over the shoal; and to widen the Pegu river, by cutting off some of its left bank, and so allow the water to pass without pressing too hard on the spur works at Pussendoon. The portion colored light red on the plan, shows the form which the banks should take in order to produce these results.

There is every reason for believing that, if the rivers be shaped as now proposed, no shoal would ever form at their point of junction; but it is not so certain that a current will be produced sufficiently strong to remove the present shoal without some other aid. There are, however, strong grounds for believing that even this will be effected,—one is, that the sand forming the shoal is so fine, and consequently so easily removed, that a very slight increase of current will do it; another is the fact, that an increase in the fresh water discharge down the Rangoon river, really did wash some of it away, although the current was not confined within proper limits, nor was it well directed. However, if the works alone will not remove the shoal, they will certainly do so if the surface be stirred up and put slightly in motion. They will have the effect of making the current on the shoal as strong, and as regular as it is above it, and so, the only reason why it should not move the sand there, as it does above, is that it may have become consolidated since it was dropt; if it has, some artificial means of loosening it must be adopted.

The class of works which will best economically accomplish the object in view is a point requiring much consideration. It is evidently impracticable to shape' the banks, as desired, by filling and forming them by labor alone. The least expensive way of doing it, is by constructing works which will tend to produce the desired result, by checking the current, collecting silt, and thus forming up the banks from the vast quantity of material carried by the river itself. The plan which seems best adapted for this purpose is the construction of two strong spurs to form the main barrier to the current, and the core from which to extend small works to collect silt to complete the form. These spurs are shown in the plan in dark red, the most important of them that on the Pegu side, will be a heavy work, owing to the depth of water in which it must be built. As shown on the plan, about 1,200 feet of it will be in water of from four to five fathoms; there does not, however, seem to be any better or more economical way of doing what is required. The spur on the Rangoon side is in comparatively shallow water, and will be neither difficult nor expensive to construct. These two large works should be first constructed, then small ones thrown out from them to form up the banks by the collection of silt to the shape shown on the plan. The small spurs shown on the plan, both on the Rangoon and Dhallah banks, are drawn merely to give an idea of what is intended; the experience gained in the construction of the main works and the result of their action, will be the best guide in fixing the position of the minor ones.

In considering the form which the works should take, their effect on the Pussendoon creek has been carefully considered, as it is known to be a very valuable auxiliary to the port. The tendency of those described will be to improve the creek,—the double spurs protect it from being crossed by the currents of either river, the flood tide will have a more direct run into it, consequently more water will flow up, and a good flood always return a good ebb scour; both flood and ebb would be well directed, so that there is every reason to believe that the entrance to the creek will be improved.

It has been noted that the width of the river at the shoal helps to maintain the impediment; there also seems to be a tendency just now, to form a kind of back channel on the right bank. This is a decided evil, any channel formed there would never be a good navigable track; a bad one would be useless, and it would tend to neutralize the effects of the works on the opposite side; hence it is decidedly desirable that this back channel should be closed, or at least prevented from enlargement. The best way of closing it will be to throw out a spur or spurs, from the bank, near the commencement of the shoal to turn the current out towards the centre of the river. Large or very permanent works, will not be required; something to train the current gently away from the bank to commence with, then, as a shoal forms by the obstruction, gradually extend the work,—outward and downward, as may be required. By following up a systematic plan of this kind, the bank may be easily brought out to the shape desired.

It is probable that, as soon as the spur which is to be thrown out from Pussendoon point begins to act, the current will press hard on the opposite bank of the Pegu, and thus wear off the corner which is to be removed. If the current alone will not cut it off, other assistance must be given. Excavating it even to low-water mark would be a very expensive work; before attempting it, every means of aiding the current to cut it should be tried. Anchoring boats along a bank, within 10 or 12 feet of it, very often causes rapid erosion; this should be tried as far as practicable; the boats employed on the works might be made to use the site as anchoring ground as often as possible. Next, the hardest bits of the earth forming the face of the bank might be excavated. Lastly, if more be necessary, a narrow slip along the whole face might be cut away, leaving the bank as nearly perpendicular as possible, so that when the current acted on it, it might tumble in.

The material to be used in the construction of the works is of course a matter of great importance. Indeed, if there were not considerable facilities for collecting it on unusually moderate terms, the works proposed would be so costly, as to deter many from undertaking them at all: everything required, however, is easily obtained, and comparatively cheap. For the deep-water part of the two large spurs, stone is decidedly the best material to use; timber of the length required is very expensive, and so is labor to fix it; stone, on the other hand—within certain limits as to quantity—is easily procured and unusually cheap. The Master Attendant states that, at least 30,000 tons per annum of ships' ballast, can be dropt on the site of the proposed works at the rate of eight annas a ton; if so, there can be no doubt whatever that it is the cheapest and best material to use for all works, in water of more than two and a half fathoms. It is not at all certain that it is not cheaper for works in much *less* depth, but there are decided advantages to be gained from using more than one kind of material. First, the quantity of any one kind available will not be enough to allow of the works being carried out rapidly, and rapidity with works of this class, means economy. Next, a sufficient number of boats adapted for conveying ballast could not be had without a very large outlay for plant. Again, by using different kinds of material, different kinds of labor will be brought into use, permitting the works to be carried on rapidly without great pressure on any one class; and, lastly, by this means, experience will be gained, while the work proceeds, as to which class of material is best adapted to the end in view, both in point of economy and of time. This last reason is not the least important; for there is no rule which is applicable to all cases, under all circumstances; and the experience gained from close observation during the progress of a work of this kind, is often worth more than the best professional opinion. With this reservation, the following general rule may be adopted:—For works in depths of over 2½ fathoms, use the largest stone ballast available; small stone, used merely to fill up the interstices between large ones, being useless—wasted in fact. The base of the spur may be laid out a few feet more than double the height; the stones will stand well at slopes of 1 to 1, and there is no necessity for more than a few feet in width at top. In depths of from one up to two and a half fathoms, ordinary guide and sheet-piling, like the sides of a common cofferdam, with a line of brush-wood about 6 feet wide and 2 feet deep sunk on either side, to prevent washing about the feet of the piles. In depths of less than one fathom, two rows of jungle-wood piles, driven at distances of about 3 feet apart each way, the space between being filled in with brush-wood secured down with clay, or stones, &c.

As the depth of water in which the large spurs must be built is considerable, it will be necessary to adopt every available means which may be likely to economize material; the following plan has often been found to effect a great saving. The spur should at first be laid out only large enough to allow of its being carried up to the level of low water; as it will generally be found that, when the stone-work is carried up to this level, a shoal will be formed on one side, or, perhaps, on both sides of it. When the shoal is completely formed to the level of the spur, a line can be set out on the shoal and old spur, of dimensions sufficient to allow of its being carried up to half-tide level. Half-tide level will generally be found high enough to carry the stone-work; but if, when the shoal forms up to this level, more be found necessary, another can be laid to be carried up to ordinary high-water. By proceeding in this way, a very great saving may be effected if the scheme be successful; while, if it fail, that is, if silt do not accumulate as the work proceeds, the worst that can happen is, that the spur must be carried up as it would have been if the attempt had not been made.

When building in currents, the site of the spur should be covered *completely over* with about a foot deep of small stones, or very coarse gravel, before any part of the work be carried up more than a few feet in height. This precaution is necessary whatever kind of spur be used: if it is not attended to, the current, which always runs round the spur-head, will deepen the site of it as the work proceeds, so that a work which was intended to have been in 10 feet of water may be really carried out in 20. The deepening goes on gradually and almost imperceptibly: but the loss of material caused by it is often very great. In the case of small pile and brush-wood spurs, the piles may be all driven first, and then a thin layer of brush-wood put over the bottom, before any part of the body be raised.

It has been already explained, that the data on which an opinion has been formed, as to the nature of the materials in the shoal, are not sufficiently accurate to warrant the commencment of works; it is possible that there may be some hard material in some part of it which could not be removed by the means proposed. In order to settle this part of the question conclusively, a set of borings should be made in the positions shown on the plan: they should be carried to a depth of four fathoms below low water. The work is not difficult; all the apparatus required for it is in store at Rangoon. If only sand be found, borings on the sites marked on the plan will be sufficient; but if laterite, or any other hard material, be found, as many additional borings must be made as will fix accurately the position and extent of the hard spots. If there be hard material enough to affect the scheme of improvement proposed, the question must be re-considered. It is, however, all but certain that the whole obstruction is formed of sand alone.

The survey attached to this Report is not sufficiently detailed, nor sufficiently extensive to answer for a working plan. It is quite possible that a better plan may show that some modification of the details of the design, now submitted, may be an improvement: the main features, however, would remain unaltered. Mr. Pearson is now making a survey of the river, so that there is a very favorable opportunity of getting a good plan of the shoal. He should be instructed that an accurate survey of the Hastings' Shoal is required: it should take in the shoal, a distance of two miles above, and the same below "Monkey Point," a distance of two miles over the Pegu river, and of one mile up Pussendoon creek. The banks should be accurately fixed, and the lines of soundings on his survey should be referrable to fixed points on the banks. The soundings should be within distances of 200 feet of each other, and very accurate in the lines of the works, as laid down on the plan. The survey should be plotted to a scale of 1,000 feet to an inch. The work, as laid down on the plan attached to this Report, should be transferred to Mr. Pearson's survey, so that any modifications considered necessary, owing to a difference in the surveys, may be made.

ESTIMATE OF THE COST OF CARRYING OUT THE PROPOSED WORKS.

		RS.	RS.
Spur at Pussendoon point—			
Stone ballast, 80,000 tons, at 8 annas, ...	=	40,000	
Gauge and sheet piling, 400 l. ft., at Rs. 10, ...	=	4,000	
Small spurs for silting up, 5,000 l. ft., at Rs. 1.	=	5,000	49,000
Spur at Monkey Point—			
Stone ballast, 40,000 tons, at 8 annas, ...	..	20,000	
Gauge and sheet piling, 600 l. ft., at Rs. 10, ...	..	6,000	
Small spurs for silting up, 5,000 l. ft., at Rs. 1, ...	..	5,000	31,000
Silting up the back Channel—			
Stone ballast, 10,000 tons, at 8 annas, ...	..	5,000	
Gauge and sheet piling, 1,000 l. ft., at Rs. 10, ...	..	10,000	
Brushwood spurs, 5,000, at Rs. 1, ...	..	5,000	20,000
Cutting away Pegu Point—			
Say		..	10,000
			1,10,000
Contingences, 20 per cent., ...		..	20,000
Total,		..	1,30,000

CALCUTTA,
March 8th, 1866.

NOTE.—This estimate does not profess to show more than a general average cost. The work should not cost more.

H. L.

No. CXXIII.

PRACTICAL NOTES ON ROADS AND CANALS.

By T. Login, Esq., C.E., *Exec. Engineer, 8th Division, Grand Trunk Road.*

In selecting a new line of road, the following suggestions may be of service in assisting the Engineer in determining what line should be adopted.

The average section of our Imperial roads in upper India may be taken at as follows:—

Breadth of top of embankment, 40 feet.

Height of embankment, 4 feet.

Slopes, 5 horizontal to 1 perpendicular.

Breadth of arches of bridges, 30 feet.

Breadth of metal, 16 feet by 9 inches thick.

Rate of earthwork, Rs. 2-8 per 1,000 cubic feet.

Rate of consolidated metal, per inch per mile, Rs. 750.

Cost of maintenance, per mile yearly, Rs. 750.

Cost of drain bridges, per running foot of water-way, from 75 to 100 Rs. up to 15 feet span.

Cost of large bridges, from 300 to 400 Rs. per foot.

The rates here given will be found a close approximation to the actual cost, only that for earthwork is rather over than under what the probable expenditure may be.

From the above data we obtain the following comparative cost of embankments, bridges and metal.

Cost of one mile of embankment $(40 + 20) \times 4 = 240$, @ Rs. 2-8 per $1{,}000 = 0{\cdot}60$ or Rs. 0-9-7 per foot.

$\therefore$ One mile costs $5280 \times 0{\cdot}60 =$ Rs. 3,168.

The cost of drain bridges is $\frac{75 \times 100}{2} =$ Rs. 87-8 per foot.

Therefore, the cost of one mile of embankment equals only 36 feet of water-way for drain bridges, while only 10 running feet of water-way of such bridges as that over the Markunda equal the cost of one mile of embankment.

One mile of metal costs $750 \times 9 =$ Rs. 6750, or more than double the embankment; and taking the maintenance of road, at Rs. 700 a year for metal, and Rs. 50 for earthwork, at 20 years' purchase, we have for metal $700 \times 20 =$ Rs. 14,000 a mile; therefore the cost of metal is Rs. 20,750 a mile, or more than six times the cost of the embankment.

From the above, therefore, it is evident—First, that all cross drainage should be avoided where practicable, and that *the height of embankments should not be so much taken into consideration as the length of road*, so as to save metal.

Secondly, as the cost of metal is such an important item, and as this so much depends on the distance from the quarries in selecting a new line, *the proximity to kunkur beds should form a very great reason for adopting one line in preference to another.*

Supposing the wear and tear of metal to be 7,500 cubic feet a year per mile, and that 8 annas is saved for each mile the road is nearer the quarries, the actual saving would be 7,500, @ Rs. 0-8 = Rs. 37-8 a mile, which at 20 years' purchase equals Rs. 750. Thus, if 4 miles could be saved in carriage, it would equal the first cost of the embankment nearly; or the road may be lengthened one-sixth between two points without adding to its cost; that is $16{\cdot}66$ per cent. longer, which would admit of a diversion of about one-third of the total distance out of the straight line.

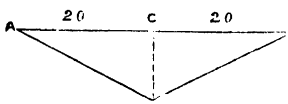
Lastly, where nothing is to be gained by deviating from the straight line, either in avoiding drainage or being nearer kunkur beds, the embankment may be raised as follows, without adding to the cost of the road, with the following rates for earthwork :—

Height of embankment up to 5 feet, Rs. 2-8 per 1000
„ „ above 5 and up to 10, Rs. 3 per 1000
„ „ 10 and up to 15, Rs. 3-8 per 1000

Saving in distance	1 mile in	2, or	$\frac{1}{2}$,	embankment may be raised to	13·00 feet.
	1 „ „	3, „	$\frac{1}{3}$,	„	10·00 „
	1 „ „	4, „	$\frac{1}{4}$,	„	8·40 „
	1 „ „	5, „	$\frac{1}{5}$,	„	7·45 „
	1 „ „	6, „	$\frac{1}{6}$,	„	6·64 „
	1 „ „	7, „	$\frac{1}{7}$,	„	6·10 „
	1 „ „	8, „	$\frac{1}{8}$,	„	5·80 „
	1 „ „	9, „	$\frac{1}{9}$,	„	5·50 „
	1 „ „	10, „	$\frac{1}{10}$,	„	5·33 „
	1 „ „	15, „	$\frac{1}{15}$,	„	5·00 „

That is, if the road can be shortened from $\frac{1}{20}$ to $\frac{1}{15}$ of its length, add one foot to height on an average throughout the whole length of embankment; from $\frac{1}{15}$ to $\frac{1}{9}$, add $1\frac{1}{2}$ feet; from $\frac{1}{9}$ to $\frac{1}{7}$, add 2 feet; for $\frac{1}{6}$ and $\frac{1}{5}$, add 3 feet; if $\frac{1}{4}$ is gained, add $4\frac{1}{2}$ feet; where $\frac{1}{3}$, add 6 feet; and where the distance is halved, add no less than 9 feet to the height of embankment. That is, supposing a valley to intervene, which is one mile broad and requires an embankment averaging 13 feet high to cross it, but by going a circuitous road which would avoid this bad ground, but add one mile to the length of the road (all other circumstances remaining the same along the line), it is as *cheap* to make the 13 feet embankment as to go the more circuitous route, while travellers are saved one mile. In other words, it is very seldom a road should be made to deviate from the straight line on account of earthwork only, except in a hilly country, where steep gradients would interfere.

Considerable deviations can however be made from the straight line without adding much to the actual length of road, as will be seen by the following:—Let A and B be (say) 40 miles apart, and half way, at the point C, lay off the perpendicular line CD. Suppose CD is one-tenth of AB, the line ADB will only exceed AB 2 per cent. The Engineer, therefore, at half the distance between the two points to be connected, has a breadth of 8 miles to select from, without adding more than 2 per cent. to the whole length of road. If $\frac{1}{6}$, or 16·66 per cent. be added, (the limits where the cost of embankment and maintenance of metal equal each other,) the divergence may be upwards of 13 miles on either side. Such a deviation from the straight line is much too great; so, in practice, if cross drainage can be saved to the extent of saving only 14 square miles in a distance of 40

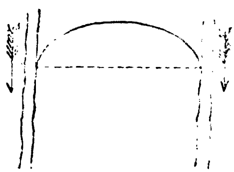


miles, it comes to the same thing as to cost, as adding 2 per cent. to the length.

Thus, Rs. 3,168, cost of one mile

$$\times \frac{(2 \text{ per cent. on } 40 \text{ miles} = 0{\cdot}8) \times 7 \text{ (cost of earthwork and metal)}}{87{\cdot}5 \text{ (cost of one foot of water-way)}} = 202{\cdot}7$$

and by page 135, of Vol. II. of Professional Papers, Colonel Dickens allows 42 feet of water-way for 3 square miles; but, by adding 2 per cent. to the length, we do not merely gain 14* square miles, but $\frac{40 \times 4}{2}$ = 80 square miles, where the road runs at right angles to the drainage.



Therefore, there can be no doubt that where we have a road (say) crossing from the Ganges to the Jumna (all other points being the same), that instead of it being a direct line right across, it should curve considerably upward, thus—

The extent of deviation in a distance of 40 miles, and the per centage added to the length of road is here given :—

	Miles.	Per centage		Miles.	Per centage.
1	in	40 = 0·15	11	in	40 = 12·41
2	„	40 = 0·50	12	„	40 = 14·28
3	„	40 = 1·24	13	„	40 = 16·18
4	„	40 = 2·00	14	„	40 = 18·10
5	„	40 = 3·00	15	„	40 = 20·00
6	„	40 = 4·27	16	„	40 = 22·12
7	„	40 = 5·62	17	„	40 = 24·18
8	„	40 = 7·11	18	„	40 = 25·60
9	„	40 = 8·80	19	„	40 = 27·51
10	„	40 = 11·00	20	„	40 = 29·33

From which it appears, that so long as the deviation is kept within moderate distances, the additional length is little; for even up to one-fourth of deviation of the total distance, only 11 per cent. is added; but where this is exceeded, the per centage increases fast.

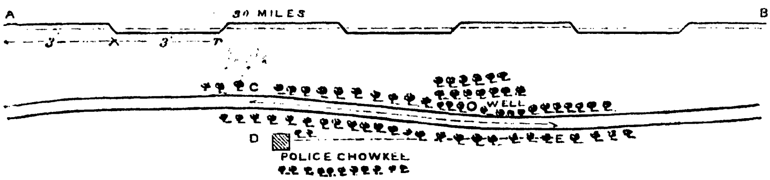
Suppose the bearing between the two points to be connected is 90°, or due east and west; so long as the bearing of no part of the line does not exceed 100° or less than 80° for all practical purposes the road will be nearly as short as the direct line, while it gives the Engineer considerable scope for selecting his line. In doing which, he should consider, first,

* $\frac{202{\cdot}7 \times 3}{42}$ = 14 square miles.

the Drainage; secondly, the supply of Metal; and lastly, the Earthwork, which, though at first sight it appears the greatest, is in reality insignificant in comparison to the other two items.

A straight line is undoubtedly the shortest distance between two points, but nothing is more monotonous than to have to march along a straight road. In fact, one should never be able to see more than three miles along any road; and this can be easily accomplished by passing round a village or a clump of trees. Curves, however, are unsightly in an open plain, unless there be some natural feature in the country necessitating a curve, such as to cross a stream at right angles, or to avoid low, marshy ground, or some high mound. In the latter case the mound can be taken advantage of in hiding the road. Where, however, all is one extensive plain, as one often meets with in India, to put a curve in a road and not to *hide* it, appears as if a mistake had been made in lining it out, which is worse than a continuous long line.

Curves may however be given at every three miles, so that no portion of the road can be seen for a greater distance, and the road greatly improved, not only in appearance, but also in comfort to travellers. Suppose the distance between the two points it is necessary to connect is 30 miles apart, and that the country is one open uniform plain. The shortest line would no doubt be one uniform straight, but it would be too tedious, and would involve long marches of 15 miles each, with nothing to break the monotony of the march. By introducing Ogee or S curves at every three miles, and planting two clumps of trees near them on either side of the road, with a well in the centre of one of them, the road could only be seen along three miles of its length, and wearied travellers would have comfortable shade with water to drink. A Police Chowkie could be placed in the other clump, so as to afford protection to property.



Supposing DE to be equal to 1000 feet, and CD equal 50 feet, then $\sqrt{1000^2 + 50^2} = 1001{\cdot}24$ feet; or nine of these curves may be introduced, and only add to the length of the road in a distance of 30 miles, some four yards. In practice, therefore, the distances become one and the same, and as to lining out, the Engineer need only mark out the straight dotted line and level along it, leaving the classies to mark out the offsets and lay out the Ogee curves with a chain and graduated set square, which any intelligent man could be taught how to do in a few hours. This is done by setting off at, say every 100 feet, at right angles, any distance the Engineer considers necessary, and then placing banderoles on the two last pegs, when 100 feet more is measured in the line of the banderoles and another offset fixed, and so on. This plan is to be found described in most engineering works on laying out roads, railways, &c., and calculations are given to find the radius of the circle described with given offsets, &c., &c.; but it is not the intention of this paper to give mathematical details, but simply practical suggestions.

In practice, therefore, it will be found most convenient to lay off the curves, not in circles, but by polygons; that is, supposing the first offset be 1½ inches, the second would be 3 inches, the third 6 inches, next 9 inches, then 1 foot, 15 inches, and so on. When the centre of the desired curve is reached, the offsets to decrease in a similar manner. By introducing one length of chain in a straight line after the last offset of the curve, the second portion of the Ogee can be marked off in a similar manner; thus a set of curves can be laid down on the ground by an intelligent classic in less time than it would take to survey and calculate out the proper offsets.

The curves, also, having more the character of parabolas, that is, commencing flat and ending in the same manner, while the centre is sharp, look well on a road, and by many have been considered better for railways and canals. With the railway there is no quick change of the course, which sometimes causes the engine to run off the line. With canals such a curve is better than an arc of a circle, as it causes less sudden derangement of the flow of the water; for it is evident that the tendency of water is to deepen the bed where the velocity is greatest; that is, along the extrados; thus there will be a much greater body of water passing down on the one side than the other. Consequently the water will naturally take to the line of least resistance on leaving the curve, and instead of flowing down in the direct line of a canal, will attack the opposite bank.

In marking out roads through the plains of India, for all practical purposes, if the levels are known at every 400 feet, a sufficiently close approximation to accuracy will be arrived at to calculate and estimate the earthwork. At each of these pegs, 400 feet apart, a bamboo should be driven to the required height, and on this bamboo should be marked the height* and number of the peg according to the section. Also much time is saved by cutting on the ground at a little distance from the line the number of each fifth station in large figures.

The barrow pits or tanks from which the earth for the embankment is obtained, should also be uniform in size, say 150 feet long with a space of 50 feet intervening. This enables the Engineer to check the measurements at any time, and prevents a flow of water parallel to the road, while it stores up water in the rains that can be used for consolidating the embankments, a matter of great importance in the future maintenance of the road. These tanks should not only be uniform in length, but also of given breadths—advancing by 5 feet at a time—such as 20, 25, 30, 35, and 40 feet broad, according to the quantity of earth required. By this means there is no necessity for measuring the length or breadth, for the eye can at once detect any error; so only the depths are required to be taken, and by having the contents readily calculated out in a tabular form in one's note-book, the content and cost of each tank is known at a glance.

In practice, after the height of embankments is fixed at every 100 feet along the centre line, an intelligent classie with a good eye and an optical square can mark out the slopes and tanks, and the whole can be done for less than 10 rupees a mile, that so the Engineer's time need not be taken up with such details when once he has seen the work properly started.

By this arrangement also, the breadth of land required to be taken up is at once settled, and as it consists of long parallel strips, all disputes about areas and boundaries are avoided, while the work of the Civil Officers is much reduced. Much time and money would be saved, and much more satisfaction would be given to the zemindars, if the Executive Engineer were permitted to walk up the line and pay the villagers on the spot the compensation for whatever trees, crops, &c., there may be on the line, taking receipts for the same. He should always give Rs. 25 per cent. over the market value of what is destroyed. If the

* Allow 1 foot for sinking in every 7 feet of height.

loss of time and the pay of Civil Officers' Subordinates be taken into consideration, the cost to Government far exceeds Rs. 25 per cent., while the villagers are better satisfied by getting ready money. If the Executive Engineer cannot be entrusted with paying such compensation, neither should he be trusted with paying his workmen.

In conclusion, it may be stated that portions of our Grand Trunk Road are now actually costing more to keep in repair than a line of railway; the latter being about 100 rupees a month a mile, while portions of the Grand Trunk Road are costing upwards of 120 rupees a month a mile. With such an enormous expenditure, therefore, increasing year after year, a time must be soon reached when all the available money will be swallowed up in repairs, unless more funds be supplied by local taxation, or some other means be devised for the traffic, which is daily increasing.

The only way therefore that appears to meet the difficulty is to have Navigable Canals. The chief cost of these works will be the first outlay; but after that, the maintenance will be, comparatively speaking, little beyond the loss of a little water by evaporation and absorption; but as the velocity will be slight, the bed can be puddled, and thus the leakage reduced to a minimum.

Supposing that the loss of water by absorption and evaporation, including lockage at the lower extremity of a canal, is in all $1\frac{1}{2}$ feet a second per mile, and that it will require 500 miles of navigable canal to connect Roorkee, Saharunpore, Kurnal and Delhi with Allahabad. Also that 100 yards average breadth of land is required for the canals, and that an acre of land is worth Rs. 40, while a cubic foot of water per second is worth Rs. 400 a year.

We have $500 \times 1\frac{1}{2} \times 400 =$ Rs. 3,00,000, and one square mile of land required for every 17·6 miles of canal or $\frac{500}{17 \cdot 6} = 28$ square miles. Then $\frac{28 \times 640 \text{ acres} \times 40 \text{ rupees}}{20 \text{ years' purchase}} =$ Rs. 36,360; or in rough numbers, the expenditure on land and water would equal Rs. 3,50,000, or about the present expenditure on two divisions of the Grand Trunk Road; independent of the expenditure from the local funds on the maintenance of roads. Now, if the navigable canals would relieve the roads of one half of the traffic, it appears that were water communication adopted, the saving of wear and tear on the Imperial roads alone would almost cover the compensation for land and loss of water. Therefore, if Government gave the land and the water for nothing to a private company; with the *present traffic*, Government would be no loser.

These canals should run through the centres of the chief cities, and the full 100 yards in width should be taken up, the company paying the compensation for all buildings, &c. This, though a great outlay at first, would ultimately pay well; for supposing 100 feet to be required for the canal, 100 feet for roads 50 feet broad on either side; there would still remain 50 feet also for building sites, the rents for which would fully pay for the compensation.

The surface level of the water should be at least 1 foot above the roads, so that there could be no drainage into the canal, and there would be always a flow of clean water through our chief cities. With an open space 200 feet wide through every town, a flow of clean water, with the merchandize brought up to the door of every shop-keeper, not to speak of the water power available at every lock, it is difficult to imagine how much the country would be benefited without putting Government to any extra expense, while the projectors of such works would find it highly remunerative.

Judging from Major Crofton's estimates, the probable cost per mile for a 50 feet broad navigable canal should not exceed Rs. 20,000

To this add compensation, management, &c., 10,000

Total, 30,000

or 500 miles of navigable canals may be constructed through the richest portion of India to connect its chief cities, at a cost of not more than one and a half million pounds sterling.

Taking the average slope of the Doab at 17 inches in the mile, and that of the canal only 6 inches, 11 inches have to be got over by locks in every mile, or in all say 450 feet and taking the discharge at 250 cubic feet a second passing through these locks, we have (*see* Beardmore's Hydraulics) water power per foot of fall as follows:—

		Horse power.
Undershot wheel,	... ...	9·9 × 450 = 4,455
Breast "	... ...	15·6 × 450 = 7,020
Turbine "	... ...	21·3 × 450 = 9,585

Or an average of 7,020 horse power.

Supposing only one-half of the power be made use of, we have distributed over the country 3500 horse-power, available for sugar, oil and grain mills, &c., &c.; and taking each horse-power at the low rate of 8 annas in the

24 hours, we have at once a return of 4 per cent. on the total outlay from this source alone, independent of navigation. Now, as it is found that it is better to run the risk of rafting down sál timber from the forests at the foot of the hills on the left bank of the Ganges to Cawnpore, and then to pull it up against the stream of the Ganges canal to near Meerut, than to cart it by the direct road, some slight idea may be formed without going into figures of the difference of cost between land and water transport.*

RETURN SHOWING COST OF TRANSPORT OF 100 MAUNDS WEIGHT OF GOODS ONE MILE.

Mode of transport.	Rate.			Probable distance travelled daily.	REMARKS.
	RS.	A.	P.		
				Miles.	1 md. = 80 lbs.
Ocean long voyages, ...	0	0	2·20	150	Obtained from report of State Engineer of New York for 1853.
American lakes, ...	0	0	4·76	...	
Hudson river,...	0	0	4·00	...	
Erie canals, ...	0	0	6·35	...	
Ordinary canals, ...	0	0	8·00	...	
Coal railways, ...	0	0	11·11	80	
Favorable passenger lines, ...	0	1	8·00	150	
Passenger lines, steep gradients,...	0	2	8·25	150	
East India Railway, lowest rate,...	0	2	1·00	150	Indian rates of transport for grains and the cheapest description of goods.
Country carts, over metalled road,	0	4	0	12	
" " country "	0	5	4·00	12	
Indian Carrying Company over the Grand Trunk Road, ...	0	6	11·00	33⅓	
Probable rate by Navigable Canals in Upper India, ...	0	1	0	12	

NOTE.—The probable rate of interest to be charged on goods would be one anna per 100 rupees daily, or 22½ per cent. nearly (22·8 per cent.) Therefore the cost of transport of 100 maunds of grain, worth 100 rupees at prime cost, conveyed by Canals a distance of 300 miles, would be—

	R.	A.	P.
Cost of carriage of 100 maunds $\frac{300}{16}$ ... ... =	18	12	0
Time of transport, 25 days, at Rs. 0-1-0, ... =	1	9	0
Total, ...	20	5	0

or nearly 20 per cent. on prime cost.

* The charge for the conveyance of goods by the Inland Transit Company along the Grand Trunk Road for a distance of less than 80 miles, is greater than the freight from London to Calcutta.

Should the rate be reduced to 8 pie a mile,

	R.	A.	P.
The cost of carriage of 100 mds. = $\frac{300 \times 8}{12 \times 16}$ =	12	8	0
Time of transport, 25 days, at Rs. 0-1-0, ... =	1	9	0
Total, ...	14	1	0

or only 14 per cent. on prime cost.

By the lowest rate of Railway charges,

The cost would be 300, at Rs. 0-2-1, ... =	39	1	0
Add time of transport, 2 days, ... =	0	2	0
Total, ...	39	3	0

or 39 per cent. on prime cost.

By country Carts on Metalled Roads,

The cost would be 300, at Rs. 0-4-0, ... =	75	0	0
Add time of transport, 25 days, ... =	1	9	0
Total, ...	76	9	0

or 76·72 per cent. on prime cost.

By country Carts on Unmetalled Roads,

The cost would be 300, at Rs. 0-5-4, ... =	100	0	0
Add time of transport, 25 days, ... =	1	9	0
Total, ...	101	9	0

or over cent. per cent. on prime cost, with no allowance made for back hire.

By Bullock Train over the Grand Trunk Road,

The cost would be 300, at Rs. 0-6-11, ... =	114	3	6
Add time for transport, 9 days, at Rs. 0-1-0, ... =	0	9	0
Total, ...	114	12	6

or nearly 115 per cent. over prime cost for the cheapest class of goods, and 100 per cent. over the lowest rate by canals.

Comparing the cost by Railway and by Canal, if the canal rate is one anna a mile, it is only one-half the railway rate nearly, and about one-third the railway rate if the charge be only 8 pie. Therefore, till the interest on the capital of prime cost makes up the difference owing to the loss of time by the canal, water transport would be preferred to railway carriage. That is, no goods would be sent by railway under ordinary circumstances that cost less than 14 rupees a maund, for

	R.	A.	P.
100 maunds transported 300 miles, @ Rs. 0-1-0, .. =	18	12	0
Interest on 100 maunds, @ Rs. 14 for 25 days, @ Rs. 0-1-0 per cent., ... =	21	14	0
	40	10	0

And 100 maunds for 300 miles, @ Rs. 0-2-1, ...	=	39	1	0
Interest on 100 maunds, @ Rs. 14 for 2 days, @ Rs. 0-1-0 per cent., ...	=	1	12	0
		40	13	0

Again, suppose one European Soldier costs the state £100 a year, or Rs. 2-11-10 daily, and that he can be conveyed by rail 1,000 miles for Rs 16 in three days, the cost to Government would be—

		R.	A.	P.
Rs. 2-11-10 × 3	=	8	3	6
Add railway charge, ...		16	0	0
Total, ..		24	3	6

To march 1,000 miles at the rate of 12 miles a day, without halts, would occupy 83 days, and Rs. 2-11-10 × 83 = Rs. 227-6-4 ; or by a quick railway he can be carried at nearly one-tenth the cost to Government than if he had to march, and his services are available 80 days sooner. The natural conclusion to be arrived at therefore is, that both quick Railways and slow navigable Canals, are required for the protection and development of India.

T. L.

No. CXXIV.

KANWAR HARBOUR WORKS.

Report by Captain W. Goodfellow, R.E.

A reference to the accompanying sketch will show that the Bay of Kanwar is sheltered from gales from the south-west, the great desideratum of harbours on the western coast of the Indian Peninsula.

A Harbour Engineer of experience was deputed in the year 1858, for the purpose of examining and reporting on the capabilities of Sedashewghur, with referance to the formation of a harbour of refuge, and he recorded the following opinion:—

"The bay is at present partially protected from the monsoon, during the time of its greatest violence, in the months of May and June, when the direction of wind is nearly south-west, but it is exposed to the west and north-west. It might be sheltered from these quarters by the construction of breakwaters of altogether about a mile and a half in length, and a perfectly quiet harbour thus formed of upwards of four square miles in area, with a depth varying from 14 to 32 feet at low water, and thus capable of accommodating, at all times of the tide, the largest descriptions of merchant ships, and all but the largest of the Royal or Indian Navy. The bottom is remarkably even, and consists of a stiff mud.*

"The facilities for the formation of these works, should they ever be contemplated, are very great, Kanwar Head consisting of granite of the very best quality. As a harbour of refuge or naval station, Sedashewghur, thus protected, would be quite equal to the fine harbours now in course of construction at Dover, Portland, Holyhead and Alderney, and I think at a less expense, compared with the accomodation afforded, than any of these.

"Although the Government may have no intention of immediately

* This is not the case; it is bad holding ground.

availing itself of the facilities here presented, I think it right that they should be brought to the notice of His Lordship, and that in any disposition of the neighbouring land, or in the formation of any works for the improvement of the navigation for the benefit of trade, regard should be had to the possible future requirements of a large national undertaking."

"There* is now no port (in the British territory) on the western coast of India, south of Bombay; for the bar at Cochin prevents any but very small vessels from entering it. It is evident that if a good port were made at Sedashewghur, the produce of North Canara, Dharwar, Belgaum, Bellary, the Raichore Doab, and some of the northern Districts of Mysore, would be exported from it, and a great import trade would also be attracted to it. In a naval, military, and political point of view, the advantages of a port on this part of the coast can hardly be over-rated."

"Even† in its unimproved state, the bay of Sedashewghur appears to possess to a certain extent the advantages of a natural harbour; these are such that even now it is capable of affording secure anchorage to a small number of large vessels, and there is nothing to prevent the use of the port as it stands at present as a harbour for trade, but the want of trade. To‡ create such trade it is only necessary to open a communication between the port and the productive country above the Ghauts, from which it is now cut off."

I have inserted the foregoing recorded observations as leading up to the decision relative to works to be undertaken; for the bay having been selected as a harbour, it was decided that the works necessary to make a port should be carried out, and at a cost not far in excess of that which the amount of shipping likely to frequent the harbour would justify.

It is proposed that at first only such works should be undertaken, as may be absolutely necessary to meet the requirements of the locality, more particularly in regard to supplying greater facilities of export for the cotton of Dharwar and the adjoining districts.

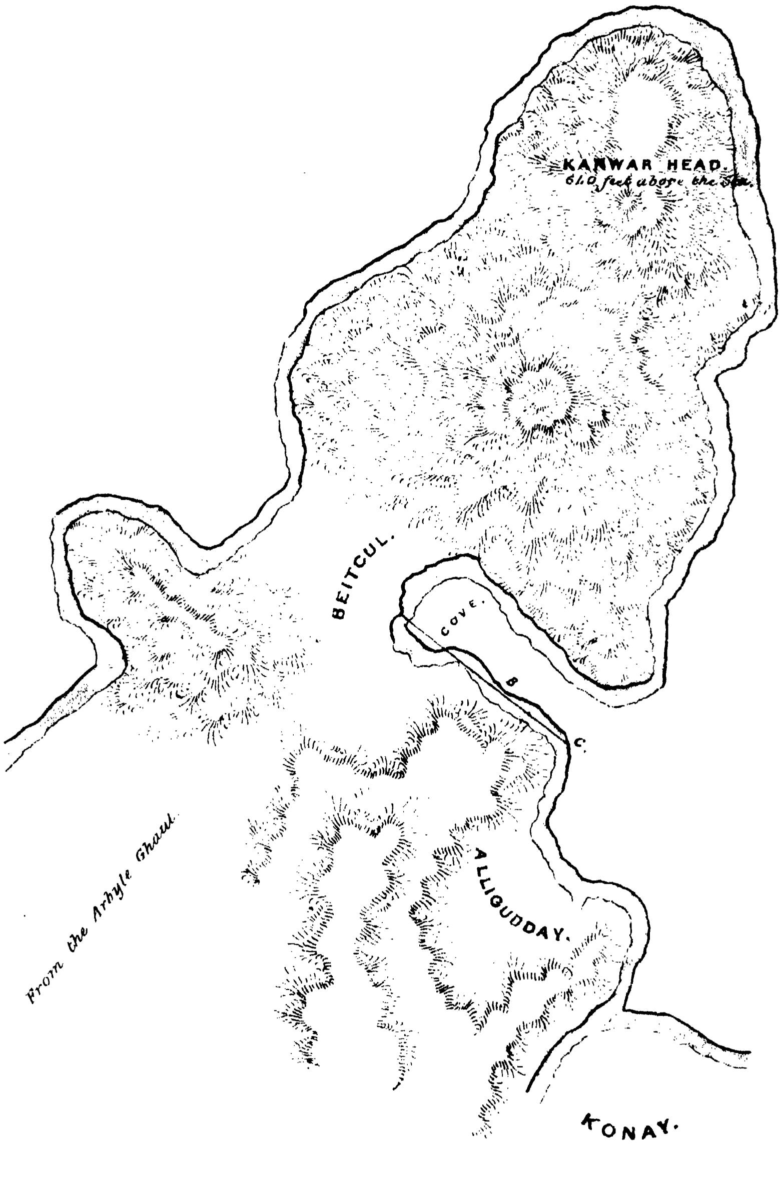
It will be admitted that a—Light-house—Wharf—Pier—Wells for Water Supply, and a Wharf Road to connect roads approaching the port, and afford access to the pier, are all works indispensably necessary for the opening of the port; and such only are embraced in this report, or pro-

* Extract minutes, dated 27th April, 1858, by Lord Elphinstone.

† Lord Stanley, P. W. Despatch to Government of Madras, 6th October, 1858.

‡ P. W. letter, from Government of Madras, 16th May, 1860.

KANWAR HARBOUR WORKS.



vided for under the term "harbour works" in the accompanying plans and estimates.

Light-house.—The position the light-house should occupy was decided on the principle which advocates the necessity for lighting dangers at the entrance of a harbour, rather than lighting the passage into the port and to the anchoring ground. I here quote from documents bearing on this subject:—

"With reference to the light-house,* we were inclined to prefer placing it on Kanwar Head rather than on the Oyster Rocks, as advised by the Marine Board, but thought that if the harbour were formed, it might be advisable to have one on each locality."

"The only portion of the scheme† which calls for immediate consideration is that relating to the exhibition of lights, which are recommended both on the Kanwar Head and one on the Oyster Rocks, which lie in a westerly direction from the shore, and one more to seaward than the site proposed for the light-house. The near proximity of these positions to each other (the intervening distance being about three miles only) would, it appears to us, make it unnecessary to build more than one light-house off Sedashewghur.

"Lieutenant Taylor recommends that a light-house should be built on Kanwar Head, which is 640 feet high, whilst the Marine Board, following Capt. Biden, advise its being built on the largest of the Oyster Rocks, with a beacon or obelisk on Kanwar Head.

"Captain Biden remarks:—The outer or western Oyster Rock offers a better site for the erection of a light-house than Kanwar Head, as that position is upwards of three miles to seaward, and in thick weather, the discovery of a light indicating the approach to danger, so much further to windward, would be a great advantage.

"The Oyster Rock is 160 feet above the level of the sea, which is a sufficient elevation for the display of a light. We presume that whether a harbour of refuge at Beitkul cove shall be determined upon or not, a good light in that neighbourhood would be very useful to the shipping in general navigating the coast, and not merely for the vessels expected to frequent the projected harbour. In this view of the subject it seems to us

* Extract Letter from Government of Madras to Court of Directors, No. 22, of 7th October, 1856.

† Extract Despatch in Marine Department, from Court of Directors to Government of Madras, No. 15 of 18th May, 1858.

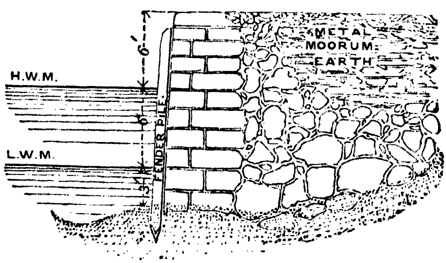
that the dangers most to seaward ought to be specially guarded against. We therefore approve of the western outer Oyster Rock as the most eligible site for the intended light-house. When the harbour of refuge shall have been constructed, a smaller light to guide vessels to the anchorage may be added in the position best suited for that purpose."

In March 1862, the precise spot for the light-house was fixed by the Chief Engineer and Secretary to Government Public Works Department, and the works ordered to be commenced.

The light will be shown from the summit of a tower 40 feet high, to be erected on the largest of the Oyster Rocks, which are three and a quarter miles from the main land; the total elevation of the light above the sea will be 200 feet. The Oyster Rocks are composed of large disrupted masses of granite; and this stone will be used in the construction of the column; the skilled labor necessary for the construction of such a column will have to be imported; no stone masons, or indeed artificers of any kind, being procurable in Canara.

The light-house will consist of a hollow column, interior diameter 10 feet, with a batter of 1 in 12 on the outside; wooden staircases, with three boarded landings inside. The necessity for great *strength* and durability has alone been considered in the selection of the design and nature of construction. The lantern ordered from England is to be one of the first order, 29 feet high from floor of lamp-room to vane, and will show a light for a complete circle.

Wharf.—The sight selected as likely to prove most convenient for the wharf is on the east of Beitkul cove. The adjacent hills come down to the water's edge rather abruptly, and the shore between Beitkul and Koney, with the exception of the sandy beach in front of Allygudday, and at the head of Beitkul cove, is composed of rough slopes of granite and boulders embedded in gravel and clay.



The manner in which the wharf walls are to be constructed is shown in the sketch, and may be described as follows:—

The rocky hill side to be blasted away; large blocks of stone coming from the hill to be roughly dressed and carefully laid, but without mortar, to form the wall, the foot of which will be 3 feet below low water-mark. The wall to be 4 feet thick at top, and built with a batter of 1 inch to a foot in the face, and with vertical back; being filled in behind up to nearly high-water mark, with dry rubble, hand packed, and above that with earth, or whatever material may come from the hill side immediately in rear. The authority for the above description of wall may be traced in the extract from a joint report by Colonel Turner, R.E., and Mr. Hope, B.C.S., given below.

"Having ascertained that there is no hard foundation in many parts of the cove, even at a depth of 14 feet, the construction of any solid masonry work would involve expensive coffer-dams, means of unwatering them, &c.; we have therefore directed that on the line BC, shown in the plan, a dry stone wharf wall be built in the sand in about 3 feet at low tide. This will probably settle, and it is possible portions of it may have to be rebuilt, but even then its cost will be trifling compared with a wall of masonry founded on the rocks, and the shell-fish in the cove will soon unite the stones."

The wall has stood well, and the shell-fish have almost closed the openings in the joints of the lower half of the wall.

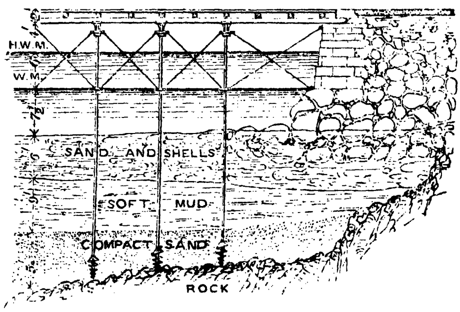
The estimates now submitted provide only for wharf accommodation to the extent of nine acres on the eastern side of Beitkul cove and in rear of the pier.

Pier.—The description of pier considered most suitable, and adopted, is that consisting of a strong wooden platform, supported on wrought-iron screw piles, 6 inches in diameter and placed 10 feet apart, so as not to interfere with currents along the shore, and to prevent silt being deposited, or the scouring of any portion of the existing bed of sand and shells, which might endanger the stability of the wharf walling.

The position the pier should occupy (*see* sketch) has been decided by Government with reference to two important considerations, viz., the point likely to be most convenient for public use in the shipping and landing of goods, also where there is smooth water during rough weather, and a sufficient depth of water to admit of the largest cargo boats being loaded and unloaded at all stages of the tide.

When the wharf walls approaching from the Beitkul and Allygudday directions meet, it is proposed to construct a suitable abutment (of heavy blocks of granite dressed and laid without mortar, founded on a base of "pierre perdue" work) to receive the shore end of the screw pile.

The sketch given below represents a section through pier abutment, and shows the position of the first rows of piles, and the depth to which the same will have to be screwed.



It was at first intended to construct a pier 200 feet in length, with a T head of 90 feet in length, both portions having a uniform width of 30 feet; and the contract for this work was taken up by Mr. George Wells, of North-Street, Westminister; the sum stipulated to be paid for the iron-work being £7,476. The contract was made by order of the Secretary of State in Council, and signed in London on the 7th August, 1863; time allowed for completion of the work being ten months from date of signing the articles of agreement.

The iron-work was examined and tested in England, shipped at Newcastle, and despatched on the 29th November, 1863; but the ship did not arrive at Kanwar till 7th June, 1864; by the 16th of July all the cargo was discharged, and everything got ready to proceed with the pier work.

I must not here omit to mention that, though the cargo was discharged during June and July, there was no difficulty or delay. The ship (600 tons burthen) was moored at the mouth of the Beitkul cove, and about 80 yards from the wharf; the wrought-iron piles, 36 feet long and 6 inches in diameter, were delivered into a lighter out of the bow ports of the vessel, which were scarcely a foot out of the water. This fact speaks for itself, and may be received as early record of the capabilities of this natural harbour, as a place of refuge from all that is to be dreaded during the south-west monsoon. After a few rows of piles had been screwed down, it became apparent that owing to the peculiarly treacherous character of the beds of sand and mud, it would be necessary, in order to secure perfect stability, to screw the piles to a very great depth, greater indeed than is usual for such structures; under these circumstances, and considering that if the pier were shortened, there would be only $7\frac{1}{2}$ feet of water, instead of 9 at low water spring tides, in front of the pier, it was decided to convert the pier into a landing stage about 100 feet square, and make use of the materials for this purpose—running out the landing stage in the same direction as the intended pier, and mounting the cranes in the positions it was originally intended they should occupy.

The landing stage was completed on the 23rd November, 1864, and cannot fail to prove most useful; for the largest cargo boats built may be alongside at all stages of the tide, and heavy bulky goods will only have to be moved 100 feet from the wharf, instead of 230, to be brought under the cranes.

The first shipment of pressed cotton, 3000 bales, for England direct, is now being made (20th December, 1864), and the wharf and pier were ready just before required by the mercantile community.

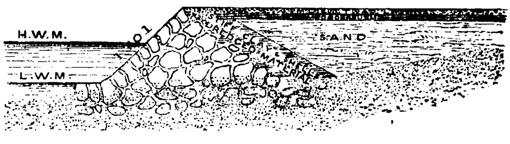
Wells, Water Supply.—The village of Beitkul is on the isthmus between Kanwar Head and the hilly mainland; on the north and south there is the sea. The surface of the isthmus is quite flat, and but little above high-water mark; it is covered with sand to a depth of 4 feet, below this there is yellow clay, and then a bed of laterite. At present water is obtained from rudely excavated wells and pits, which however, are very shallow; for it has been ascertained that if the laterite be pierced the water becomes brackish; the supply afforded by the above-mentioned wells is insufficient even for the wants of the village, and it would not be advisable to increase the supply by adding to the number of wells of the description now existing. The ground in the neighbourhood of the wharf has therefore been carefully examined, with a view to determining sites for deep wells which would yield a plentiful supply of pure water.

The hills on the east and west of the cove rise to a considerable height, and at the spots indicated on the plan, springs had been discovered; on the western side of the cove the small well which already exists can only be built up, as it would not be advisable to deepen it for fear of piercing a porous stratum, which, so close to the sea, might result in the water becoming brackish; but on the eastern side of the cove, almost on the wharf, a good spring has been discovered on the hill side, and the well to tap it thoroughly might be at least 50 feet deep, and would have to be blasted *out of the rock: this well, though expensive, would prove invaluable for* the wharf, and it is therefore proposed to make it 20 feet in diameter with a trough for watering cattle.

The wharf road, may be said to extend from Beitkul to Konay, commencing at a point near the head of Beitkul cove, where the road to the Arbyle Ghaut leaves Kanwar, and terminating a few hundred yards to the north of the Konay Creek, where the Kygah Ghaut enters Kanwar. The wharf road is in a hill side cutting the whole way, and a vast amount of rock must be removed except where it passes along the beach at Allegudday. There is only one stream or rather creek to be bridged (viz., the Konay nullah), but several well built drains will be required to convey the water, which, during heavy rain, rushes with violence from the steep hill sides above the proposed road.

The wharf road is to be 100 feet wide, and formed as shown in sketch below; material from the excavated portion of the hill which is not retained by the wharf wall, being protected from the wash of the sea by a stone bank, having a slope on the sea face of 1 to 1.

The surface of the wharf wall will be 6 feet above ordinary high-water mark, and the surface of the road will gradually fall away to 4 feet above high-water mark, which will be the average height of the top of the stone bank retaining the road; except for the portion between Allegudday and Konay, where, owing to the amount of rock that would have to be cut away to keep the road level, the surface rises at an easy gradient towards a ridge cutting, and then falls again towards Konay, where the road surface is only 4 feet above high-water mark. For bridging the Konay nullah in a suitable manner, an iron lattice girder bridge has been adopted; it consists of two spans, 40 feet each, supported on hollow cast-iron screw piles, carrying a roadway 40 feet wide.



The iron bridge was erected in preference to one of masonry, owing to the difficulty of obtaining foundations, and the necessity for economizing masonry supports such as piers.

The estimated probable cost of carrying out the works above briefly described, is as under:—

			RS.
No. 1.	Estimate for light-house (exclusive of expenditure in England for lantern),	.. .. ..	41,451
„ 2.	„ wharf wall,	.. ..	307,390
„ 3.	„ pier,	.. ..	77,661
„ 4.	„ wells,	.. ..	4,801
„ 5.	„ wharf road, including iron bridge,	..	655,668
„ 6.	„ steamer charges,	.. ..	45,565
„ 7.	Miscellaneous expenditure,	.. ..	18,600
	Grand Total probable cost of Kanwar Harbour works,	.. ..	1,151,136

W. G.

No. CXXV.

WATER-WAY OF THE SYE BRIDGE.

Report by LIEUT.-COLONEL C. W. HUTCHINSON, *Officiating Chief Engineer, Oudh.*

BEFORE passing the Estimate for the Sye River Bridge, on the Allahabad and Fyzabad Road, submitted on the 12th April last, Government of India remark, that the drainage area of the Sye, as deduced from the maps of Oudh, would seem to require three times the amount of water-way provided for in the project, and desire that I should submit a report to clear up this point.

This question was carefully considered when the estimate was under preparation, and the discrepancy above-mentioned was noticed, and calculations were made to show that by using Colonel Dickens' Formula for Flood Discharge of Rivers, and calculating the area of the catchment basin as it appeared on the maps of the province, the water-way necessary for a bridge over the Sye river would be fully three times that fixed by the ordinary calculations of sections and flood levels at site.

These latter however appeared to be so carefully and so certainly established; the views of the present and past Executive Engineers who had studied the subject did not differ to a great extent as regards water-way and discharge area; the site had been visited by me in October last, the features of the river had been examined, and the (probable) size of the bridge required at the site had been estimated by me, and found to agree with the dimensions fixed by the calculations as submitted to Government; the opportunities had been so good of year after year watching the volume of the river as it flowed past the ends of the new road embankments, and as it flowed under (and eventually over) a wooden bridge, which stood at the site for four years; in fact the conditions of the river at *site* of the proposed bridge seemed to have been ascertained and established so surely, that I considered that the results based on them could safely be accepted, although they were not borne out by the, as it were "check," calculations, based on the formula for volume of discharge as dependent on rainfall over the catchment basin. In sending up the project in the first instance, I might have mentioned that these calculations as to drainage area had been made, but I did not consider this necessary; the calculations had been made more for my own satisfaction than anything else, and the data not being reliable, I rejected them.

One great uncertainty in the mode of calculation by drainage area of this river was at once apparent, and prevented any reliance on the results thus obtained. The existing maps of Oudh are most incomplete as regards the course of the streams: the country in Southern Oudh is very flat, the streams generally very winding and very irregular; the waters of many streams seem during rain floods to coalesce, and the demarcation of separate catchment basins for separate streams would seem a difficult problem. It would appear from the maps, that at several points in its course, the Sye river during high floods fails to carry on, in its own channel, the waters which might be considered to pertain to its own drainage area; jheels and streams lying right and left of its course probably receiving and carrying off much of its surplus water into other adjacent lines of drainage, whose watersheds are scarcely defined. In the Oonao district, near the town of Ooras, it may be said that the flood waters of the Sye above that point are carried off in the bed of Nusseeroodeen Hyder's canal, and poured into the Goomtee below Lucknow city.

The question having been referred by the Government for further consideration, the Executive Engineer, 3rd Oudh Road Division, was directed to examine again most carefully his levels, flood marks, &c., and verify all the data furnished by them: and this he has done, and reports that all his measurements, &c., are perfectly correct. Thus the data of sections and flood marks at site stand on a yet surer basis.

It being out of the question that a survey of the whole catchment basin of the Sye river above Pertabghur could be undertaken, I determined to test the applicability of formulæ based on measurement of catchment basin, as shown by the bridges now spanning the Sye at other points;

although these bridges have not been long constructed, they have stood at all events the test of one or two rainy seasons, and the comparison here made seems to show that other Engineers have come to similar conclusions regarding the water-way of this river; that is, they have not been guided by calculations based on the apparent drainage area.

The railway crosses, near Bunnee, the Sye and its affluent the Lonee. Considering that the drainage of the basin of the Sye above Ooras is disposed of by the canal, one may assume that when the river passes under the railway bridge, it has drained a basin 30 miles in length and about 8 miles wide, or 240 square miles. Its velocity may be taken at 5 feet as a maximum, and it is carried under a bridge offering to it only 1,280 superficial feet of water-way. This bridge, however, if cut out to the full rectangular section, could offer $24 \times 20 \times 5 = 2{,}400$ superficial feet. To guard against under estimating its capacity, assume the last named figure. This with a velocity of 5 feet would give 12,000 cubic feet of flood discharge.

Now to compare this with the flood discharge due to its basin,

$$D = M^{\frac{3}{4}} \times 825\text{; where } M = 240 \text{ square miles.}$$

$$\begin{array}{rl} \log. M = & 2{\cdot}380211 \\ & 3 \\ \hline & 4)7{\cdot}140633 \\ \hline & 1{\cdot}785158 \\ \log. 825 = & 2{\cdot}916454 \\ \hline & 4{\cdot}701612 = \log. 50300 \end{array}$$

Here the discharge due to the catchment basin (even ignoring all drainage above Ooras) is more than four times the maximum capacity of the bridge.

Again, take the affluent stream, the Lonee, over which is thrown a railway bridge of 920 superficial feet, and if 5 feet be also assumed as its velocity, the volume of discharge equals $5 \times 920 = 4{,}600$. From the map it would seem that this stream had a catchment basin of about $20 \times 6 = 120$ miles.

Again applying the formula—M being equal to 120, we get $D = 29910$.

This is more than six times the capacity of the bridge. In each case it seems that the drainage area must be much less than what the map appears to show; or that, if the catchment basin be correctly shown and measured, the watersheds are so ill defined and irregular, that it cannot be exactly ascertained in what manner the drainage apparently due to any basin is disposed of: some of it escaping laterally into other basins which may be said to coalesce with it; or the soil of Oudh is with difficulty saturated, and the whole rain-fall cannot be held at any time, even after the hardest falls, to be poured off into drainage channels.

Rankine gives as the proportion of the amount of rain-fall carried off by streams to the total rain-fall, in a *flat cultivated* country, as ·5 or ·4, and Burnell shows that the discharge of the rain-fall from different soils is very different, granite pouring off all at once, gravel absorbing nearly all. The Oudh soil might be held to be about equally porous with oolites and gravels, off which he estimates the maximum flow as one-third or ·3 only.

The comparison between the actual water-way and that found by (this) theory may be once more tested.

At Roy Bareilly the Sye river is spanned by a bridge (designed by a Civil Engineer formerly in this Province) of 5 spans, each 22×30, or 3,300 superficial feet of water-way, or $5 \times 3{,}300 = 16{,}500$ cubic feet. Let this be compared with the flood discharge due (apparently) to the drainage area. This is the sum of the area above found (360) and a further course of 40×15, about $= 600$, or 960 in all.

By the formula we then get $D = 142300$. This is *eight* times the capacity of the bridge.

Even if the Sye (a winding slow river, of which the velocity is rather under 5 feet) be supposed to rush with a velocity of 10 feet through the Roy Bareilly bridge, the capacity of that bridge is still less than four times that due *apparently* to its drainage area.

These instances are simply given, as already said, to show that other Engineers have provided in bridges over this river less water-way in proportion to the supposed drainage area than that provided in the project submitted from this office in April last—whether they have provided sufficient water-way or not, I am not prepared to say, but I think that to adopt the formula above used to the Sye river, it will be safe to divide by 3 (at least), the result found by computing its *apparent* catchment basin from the maps now extant of this province. And this result is borne out in the case of the proposed bridge near Pertabghur, by that deduced from the data and observations mentioned in the beginning of this memo.

Although the question has but an indirect bearing on the point at issue, viz., the applicability of calculations based on apparent drainage area to the flood discharge of the Sye nullah, yet it will be interesting to show the results of such calculations on other neighbouring Oudh rivers, whose conditions have been more exactly determined.

The "iron bridge" over the Goomtee, at Lucknow, has stood for 20 years, and extraordinary floods have passed off safely under it. This bridge has a water-way of 4,142 superficial feet. Careful levels have been taken of the bed of the river from one mile above to one mile below, and the *natural* mean section of water-way has been found to be 8,277 superficial feet, with a natural velocity of 2·6, or a flood discharge of 21,520 cubic feet. The increased velocity due to the contraction of water-way under bridge is 5·4, and the flood discharge calculated from this velocity and the water-way of the bridge is 22,366 cubic feet. Let this greater volume be assumed as the actual flood discharge of the Goomtee at Lucknow, when it has had a course of 133 miles and drained a basin (apparently on an average) 20 miles in width. In order not to over estimate its drainage area let it be calculated as 133 × 15 feet = 1,995; say 2,000 square miles.

Then by the formula—we get D = 246780 cubic feet.

This is more than ten times the actual maximum discharge, and would require a velocity of nearly 60 feet per second to carry it through the iron bridge, and yet it is believed that the area of the catchment basin (as it would appear to be defined on the maps) is rather under than over estimated.

Again, over this same river (the Goomtee) at Sultanpore, a pile timber bridge has stood for many years, having a water-way of 5,200 square feet. Between Lucknow and Sultanpore the Goomtee drains a basin from 20 to 30 miles wide, with a length of a little over 80 miles; 20 × 80 = 1,600 square miles, is certainly under the area of this portion of the Goomtee catchment basin, but will be assumed in calculation. Thus the drainage area above Sultanpore is not less than

$$2000 + 1600 = 3600 \text{ square miles; whence } D = 3,83,420.$$

To carry this volume through the Sultanpore bridge would require a velocity of 73 feet per second; and, consequently, the flood discharge as above deduced is fully ten times larger than it really is.

One more example may be given of an Oudh stream, whose flood discharge during the remarkable flood of September, 1863, has been well ascertained. This stream is the Kullianee, which crosses the Lucknow and Fyzabad road, and its branch to Bhyram Ghât. The velocity calculated from two miles fall of the stream at Ramserai Ghât, was 3 feet per second. The course of the two miles is very winding, so that the true fall and true velocity in high floods, when the waters are rushing straight across the inundated lands is greater. In the maximum Oudh flood of September, 1863, the velocity was measured by current meter, and found to be 4·4 feet per second, and the flood section 4,036. The flood discharge on that (extraordinary) occasion was therefore 17,758 cubic feet. It is difficult to judge exactly from the map of the drainage area of this river; but the length seems to be 60 miles, and the average width certainly 6 miles, probably more. Take $6 \times 60 = 360$ square miles. Then $D = 85840$ cubic feet.

Or nearly five times the maximum flood discharge actually measured during the extraordinary Oudh flood of 1863, and I believe the area of catchment basin assumed above is *well* under what the map seems to show.

These three last instances fully bear out the conclusion arrived at, from a consideration of the conditions of the Sye nullah: that in designing bridges for any of the Oudh rivers, any result based upon the apparent area of the catchment basin cannot be depended upon, and that if calculations on this basis *are* made, the result thus obtained should be reduced at least by two-thirds to ascertain the flood discharge for which provision should be made.

C. W. H.

LUCKNOW,
21*st June*, 1866.

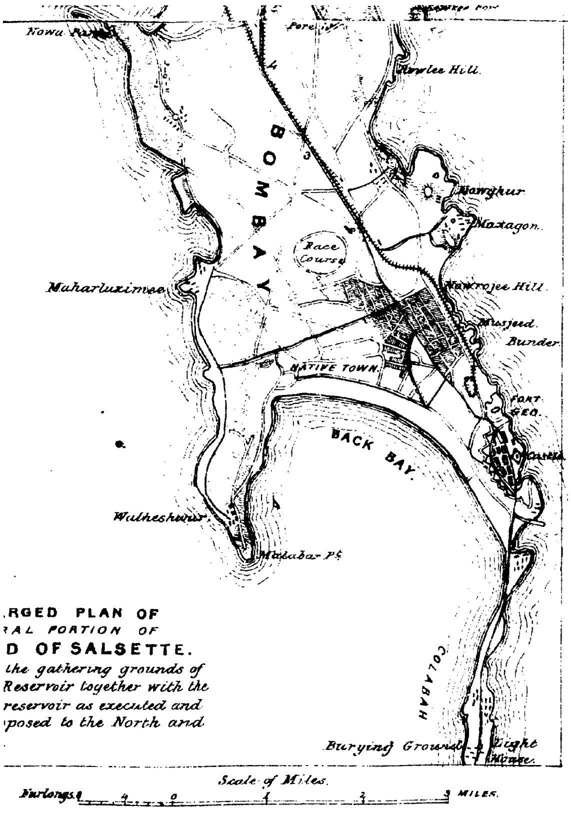
No. CXXVI.

THE BOMBAY WATER WORKS.

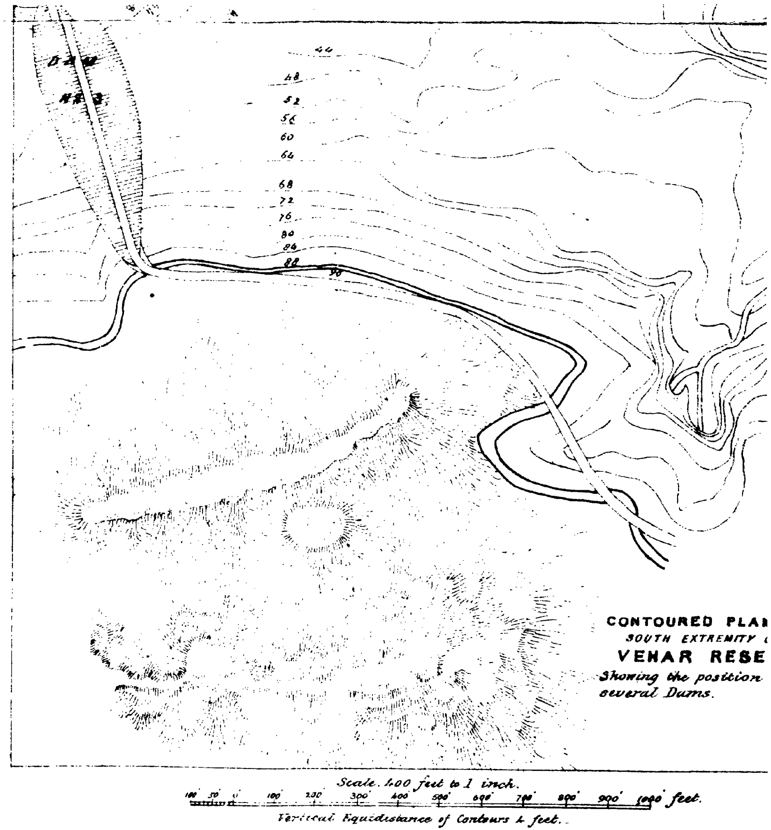
Description of the Works, recently executed, for the Water Supply of Bombay. By HENRY CONYBEARE, M. Inst. C.E. *Abridged from the Minutes of Proceedings of the Institute of Civil Engineers for* 1857-58.

EVER since the establishment of overland communication with Hindostan, Bombay has been characterized in India as the "rising presidency;" and the population of its capital has, of late years, increased in a more rapid ratio, than that of any other city in the old world. In 1833, the population was only 254,000; in 1850, it had increased to 556,000; and in 1855, it was estimated by the local government at 670,000. This rapid increase in the population, and in the importance of Bombay, is due to the advantages of its geographical position, as the nearest point of contact with Europe, and also to the excellence of its harbour—one of the finest in the world—resembling, it its configuration, the harbour of New York. Its importance and population will be still further increased, in an incalculable ratio, by the completion of the great trunk lines of railway now in progress, and which converge on the harbour of Bombay, from all points of the interior.

The water supply of Bombay had always been as deficient in quantity, as it was bad in quality; and as the population thus rapidly increased, the deficiency became occasionally so grievous, and the recurrence of the visitations, locally known as water-famines, so frequent, as to occasion the most serious alarm, both to the Government and to the public. It was evident, that a total failure in the supply, and the consequent death of tens



Nowa
Pore
Rowlee Hill.
BOMBAY
Race Course
Maharluximee
Mazagon.
Nawrojee Hill
Musjeed.
Bunder
NATIVE TOWN.
FORT GEO.
BACK BAY.
Walkeshwar
Malabar Pt.
COLABAH
Burying Ground
Light House.
.RGED PLAN OF
RAL PORTION OF
D OF SALSETTE.
the gathering grounds of
Reservoir together with the
reservoir as executed and
posed to the North and
Scale of Miles.
Furlongs 4 0 1 2 3 MILES.



DAM No 3.
44
48
52
56
60
64
68
72
76
80
84
88
90
CONTOURED PLA
SOUTH EXTREMITY
VEHAR RESE
Showing the position
several Dams.
Scale 400 feet to 1 inch.
100 50 0 100 200 300 400 500 600 700 800 900 1000 feet.
Vertical Equidistance of Contours 4 feet.

of thousands, by absolute thirst, was by no means an impossible contingency, in the event of the recurrence of any failure of the periodic rains, as severe as some that had occurred when the population of Bombay was scarcely a quarter of its present amount. In seasons of scarcity, water was imported into Bombay, in boats and steamers, from the Island of Elephanta, and the resources of the railway were taxed to the utmost, in bringing in a still greater quantity from Salsette.

The Island of Bombay is situated in the midst of the great basalt formation of Western India. It is formed by two low, wooded ranges of basalt, seven or eight miles long, running nearly parallel, at a distance of about two miles apart, and enclosing between them a clay flat, generally below the level of the highest tides. At their northern and southern extremities, these parallel ranges are united, by raised beaches of sand (now forming a littoral concrete), rising but a few feet above the sea level; and each of these raised beaches forms the margin of a land-locked bay, fringed by cocoa-nut plantations. These natural boundaries were formerly breached by the sea in several places, and the space they enclosed, comprising about three-fourths of the present area of the island, was consequently a salt-water lagoon. The breaches have, for many years past, been made good by embankments and sluices, and the lagoon thereby converted into a salt marsh, which is covered with fresh water every rainy season, and is thus being gradually brought into rice cultivation. The Island of Bombay has been connected with the adjoining islands of Trombay and Salsette (from which it is only separated by a mangrove marsh), by three causeways; and a railway bridge now unites the latter island to the continent of India. From 80 inches to 100 inches of rain-fall annually at Bombay between the 10th of June and the 20th of September, the remaining eight months and a half being without rain.

Under such geological and hydrographical conditions, a supply of water from springs was not to be expected. The population of Bombay was, consequently, mainly dependent for water during nine months out of the twelve on the rain caught, during the monsoon, in old quarries, and other shallow excavations, which, being situated in the midst of a peculiarly dense and dirty population, became so thoroughly contaminated, as the dry season advanced, that a charge "for clearing dead fish from the tanks" was an item of annual recurrence in the accounts of the municipality. It is evident, that water so impure as to kill the fish it contained, could not be drunk with impunity; and there is no doubt, but that the annual prevalence of cholera at Bombay, towards the close of the dry season, was mainly due to the extreme pollution of the only water the lower classes could then obtain. The Registrar-General's Report for 1850, affords conclusive testimony, as to the connection between cholera and impure drinking water in London; Dr. Gavin also states, that "the connection between foul drinking water and cholera is established by irrefragable evidence."

The first project for increasing the water supply of Bombay, by means of surface collection in the adjacent high grounds (obviously the only practicable plan in the case of Bombay), is due to Colonel Sykes, late Chairman of the Hon. East India Company. He proposed, nearly thirty years ago, to collect and impound the rain-water falling on the high ground at the south-western extremity of the Island of Bombay. This would, at that time, have afforded a most valuable addition to the water supply, but now it would be altogether inadequate. Colonel Sykes' plan was revived by Colonel Jervis in 1845, but without any material alteration. The second feasible scheme was that of the late Mr. Rivett, who proposed to bring the water collected and stored in the high grounds of the adjacent Island of Trombay. In 1846, Major Crawford, of the Bombay Engineers, pointed out the capabilities of the Valley of the Goper, in the adjoining Island of Salsette. This is obviously the natural, and the only adequate, source, for the water supply of Bombay, by means of surface collection. When a town is to be supplied with water on this system, and by gravitation, the valley, or valleys, debouching in the neighbourhood should be traced upwards, until some natural basin is found, at a sufficient elevation above the town, in which an adequate body of water may be collected and impounded, in storage reservoirs, by a moderate amount of embanking. The only valley answering these conditions, in the neighbourhood of Bombay, is that of the Goper. The parallel ranges which, together with the salt marsh they enclose, constitute the Island of Bombay, are merely prolongations of the boundary ranges of the Valley of the Goper; so that when swollen with floods, the waters of that stream used formerly to enter the salt marshes of Bombay, through the breaches that then existed in the northern embankments, and traversed the whole length of the island, on their way to the sea.* The central plateau of Salsette,

* *Vide* "Hamilton's Gazetteer.

which is drained by the Goper and its affluents, is bounded and intersected by ranges of hills, amongst which the occurrence of favorable sites for the storage of water might be certainly predicated.

The Goper scheme lay dormant, with the others, until the water famine of 1851. Lieutenant De Lisle was then instructed to make a preliminary survey of the valley; and soon after, the question was referred to the Author, whose report on "the amount of the existing water supply of Bombay, and the various means which had been proposed, or might be adopted, for increasing it," was published by the Bombay government. The conclusion arrived at was, that the Valley of the Goper was the only possible source whence an adequate supply could be obtained. It was recommended, that detailed contour surveys should be made, with the view of determining the capacity of whatever eligible sites for water storage it afforded; and that plans and estimates should be prepared, to ascertain the cost of rendering a supply from this source available to the population of Bombay. The course, thus recommended, was adopted by the Government, and the Author was selected as the Engineer, to prepare the surveys and estimates, and to design and execute the works.

The quantity of water required for the supply of Bombay was estimated at four thousand million of gallons annually. At the rate of twenty gallons per head per day, this supply would indeed only suffice for a population of half a million, and the population of Bombay was estimated at nearly 700,000; but, it was argued, that the proposed supply would be in addition to that derived from existing sources, and that there were peremptory pecuniary reasons for keeping down the outlay, as much as possible. On the other hand, it was admitted, that the extraordinarily rapid rate at which the population was increasing, rendered it imperative that the works should be designed with a special view to the necessity of their future extension, as the population increased.

On referring to the plan it will be seen, that the high ground, in which the Goper takes its rise, affords five admirable sites for storage reservoirs; two of which, the basins of Vehar and of Poway, are as large as lakes. The most northern of these reservoir sites is in the immediate neighbourhood of the celebrated cave temples of Kenerry, at the head of an adjoining valley; so that it will have to be connected with the Goper series of reservoirs, by a short length of syphon main. Of these basins, that of Vehar is the most capacious; but a measurement of the gathering-grounds, and contour surveys of the basin, were necessary, to determine whether the former was adequate to the collection, and the latter sufficiently capacious for the storage, of the annual water supply required, and also at what cost the supply, that might be so afforded, could be made available for public use. The result of such investigation satisfied the Author, that the Vehar basin was adequate to the collection and storage of all the water that could be required for some years, and the works for water storage, were therefore confined, in the first instance, to the construction of this single artificial lake. It was, however, arranged, that while these works were in progress, contour surveys of the other reservoir sites should be carried out, so as to determine to what extent, and at what cost, the supply might be at any time increased, by the construction of any one or of all of them.

It was essential, that the rain-fall, annually available from the area of the gathering grounds, should exceed, by a safe margin, the annual consumption, waste, and loss from evaporation, but there was no objection to the capacity of the storage reservoirs exceeding the available rain-fall of a single year. On the contrary, it was most desirable that the storage reservoirs should be made as capacious as possible, in order to contain a reserve, sufficient to meet the contingency of a deficient monsoon.

It was assumed, that six-tenths of the annual rain-fall on the Vehar gathering-grounds might be considered available for the supply of the storage reservoirs. The area draining into the Vehar basin, above the sites of the impounding dams, is 3,948 acres; if necessary, this area might be enlarged to 5,500 acres, by the extension of catchwater drains along the western slopes of the hill boundary, both to the west and on the north of the reservoir.

The mean annual rain-fall, at the level of the sea, at Tannah, five miles and a half distant from the Vehar gathering-grounds, is 124 inches. It is well known that, at high levels, the rain-fall is greater than over comparatively low-lying districts. The mean level of the Vehar gathering-grounds is at least 300 feet above the sea; and the wooded ranges that form the boundary of the basin have summits of from 800 to 1,600 feet in height. It was considered, that the rain-fall, available for the supply of the reservoirs, might be safely assumed at six-tenths of 124 inches, or 74·4 inches over the area of the gathering-grounds. At this rate the supply, available from 3,948 acres of gathering ground, would be upwards of six thousand six hundred million gallons; and that available from 5,500 acres about nine thousand million gallons. These quantities evidently exceed the requirements of Bombay for some years to come.

The storage capacity of the Vehar reservoir, which is fed by the gathering-grounds above described, is ten thousand eight hundred million gallons; deducting from this the loss from evaporation, which, at 6 inches per month for the eight dry months of the year, would amount to a little more than one thousand million gallons, there would remain nine thousand eight hundred million gallons, available for consumption. As the annual rain-fall on the gathering-grounds available for storage, greatly exceeds the annual consumption of Bombay, the water will continue to rise in the lake, notwithstanding the drain of the town, from the commencement of the rains until near their termination; or say for three months, leaving only nine months' consumption to be provided for, until the rainy season comes round again. Nine months' consumption for a population of 700,000, at the rate of twenty gallons per head per day, is rather more than three thousand seven hundred million gallons, and deducting this from the storage capacity of the lake, less the evaporation, upwards of six thousand million gallons, or nearly two years' supply, would remain in the lake as a reserve.

When filled up to the level of the waste weir, the maximum depth of the Vehar lake is 80 feet. It covers an area of 1,394 acres, and stands 180 feet above the general level of Bombay. The particulars of the three Dams, by which the water in the lake is impounded, are as follows:—

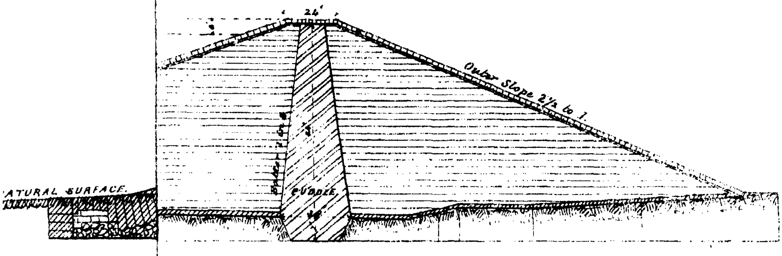
Dams.	Extreme height.	Extreme length at the top.	Earthwork.	Puddle.	Total of earthwork and puddle.	Broken stones, under pitching.	Rough stone pitching.
	Feet.	Feet.	Cubic Yards.	Cubic Yards.	Cubic Yards.	Cubic Yards.	Square Yards.
No. 1	84	835	255,706	30,910	286,616	997	26,993
„ 2	42	555	43,617	10,332	53,949	327	8,827
„ 3	49	936	106,743	14,717	121,460	659	17,797
Totals, ...			406,066	55,959	462,025	1,983	53,617

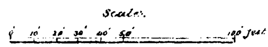
The principal Dam contains a little under 300,000 cubic yards. The top width of the embankment No. 1 (which has to carry a road) is 24 feet; that of the two others is 20 feet. The inner slope of all three embankments is 3 horizontal to 1 vertical, and the outer slope $2\frac{1}{2}$ to 1. These embankments were specified to be formed in regular layers of not more

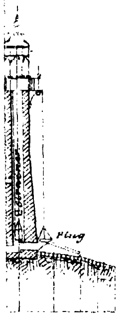
The Waste weir is 358 feet in length. It has a horizontal top width of 20 feet; and is faced throughout with chisel-dressed ashlar, set in cement. A breakwater is affixed to the inner margin of the waste weir, to prevent the water being blown over in high winds.

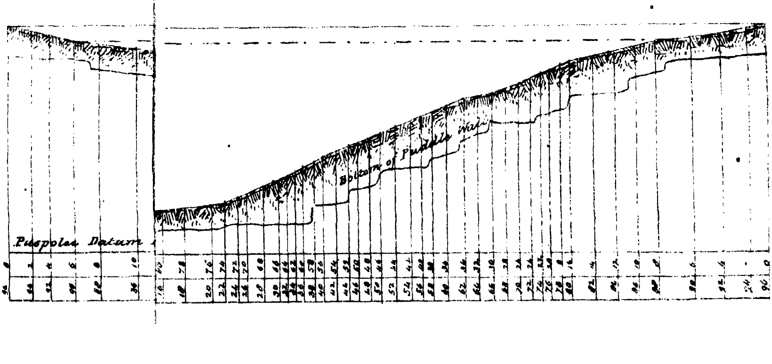
The water is drawn from the reservoir through a Tower, provided with four inlets, fixed at vertical intervals of 16 feet apart. These inlets are 41 inches in diameter, and are provided with conical plug seats, faced with gun-metal. The three inlets not in use are kept closed by conical plugs, fitted by grinding. These plugs are suspended exactly over their seats from the balcony above, and are raised, or lowered, at will, by crane-work at the top of the tower. The inlet in use is surmounted by a wrought-iron straining cage, covered with No. 30 gauze copper wire, and fixed to a conical ring, fitting into the inlet orifice, in the same manner as the plugs, and equally capable of being raised and lowered at pleasure. This strainer presents a surface of 54 square feet. The gauze is affixed to the cage, so as to admit of its being changed from a boat, when clogged, in ten minutes after the cage has been drawn up to the surface—or a plug may be substituted for the cage, and lowered to its place in the same time. At the bottom of the inlet well, and exactly over the orifice of the supply main, another conical seat is fixed, into which a similar straining cage (but with No. 40 gauge copper wire, and presenting a surface of 90 square feet) is inserted. The water thus passes through two strainers, before it starts for Bombay. The primary object of this arrangement was to obtain, in the

ECTION OF EMBANKMENT NR I. ON LINE A.B.



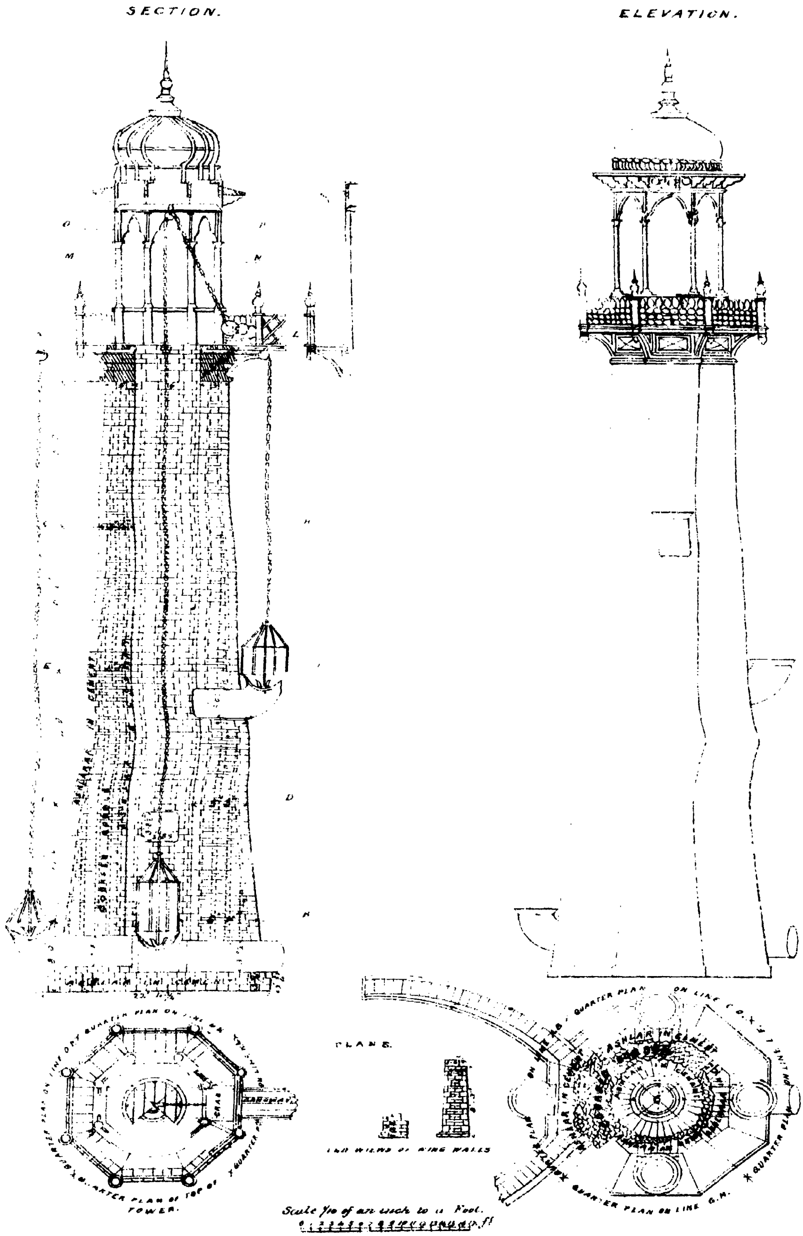






BOMBAY WATER WORKS.

INLET TOWER.



Scale 1/10 of an inch to a Foot.

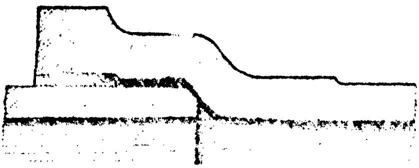
town distribution, the benefit of the additional head of water—due to the depth of the lake, which would have been lost had the water been strained (as in the more usual arrangement) at the outside foot of the dam. It was also thought advisable to avoid the use of such heavy sluice-valves as would be required for closing inlets 41 inches in diameter, in positions in which it would be difficult to get at them, for the purpose of effecting any necessary repair. Without this arrangement, the utmost head obtainable would have been insufficient for a distribution by gravitation alone.

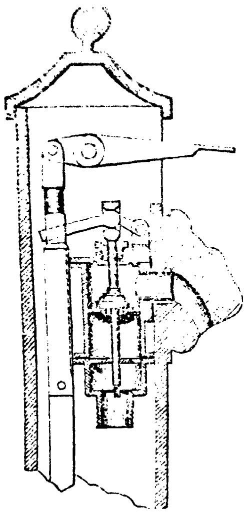
The gathering grounds are of basalt. The surface, where not covered deeply by the waters of the lake, rises with so steep an acclivity, as to have been long since denuded of any soil that could be washed away. The vegetation is all evergreen, and no human habitation is permitted, throughout the entire area of the gathering-grounds. Under these conditions, and also taking the great depth and capacity of the lake into account, the Author decided that filtration would be altogether superfluous. For the same reason, a sludge-pipe to drain the lowest level of the reservoir was deemed unnecessary. No considerable deposit is anticipated over any portion of the bottom; the little that takes place will probably be confined to the head of the lake, some miles distant from the outlet; and were it otherwise, a single sludge-pipe could have no appreciable effect, in keeping down, or scouring off, the deposit over an area of 1,400 acres.

The supply main, traversing the dam, is 41 inches interior diameter, and the metal is $1\frac{3}{4}$-inch thick. It is laid in a level trench, excavated in the rock, and filled with concrete. The portion traversing the puddle trench is supported on ashlar masonry, set in cement, puddled to a depth of 6 inches, and then arched over with four rings of brick in cement; two teak-wood washers being affixed transversely on the pipes, to prevent any water from passing between the pipes and the puddle.

At the sluice-house, situated at the outside foot of the dam, the large main, 41 inches in diameter, bifurcates into two mains, each 32 inches in diameter, both of which are eventually to be continued into Bombay; only one has been laid, in the first instance, as that suffices for the present requirements of the population. The length of the pipe, of 32 inches diameter, between the Vehar Lake and Bombay is 13 miles 6 furlongs and 160 yards, of which the last 7 miles are laid alongside the Great

Indian Peninsula Railway. The mode of joining the pipes is shown in Fig. 1. The supply is distributed through the town and suburbs, by means of branch and street mains, in the usual manner. The only peculiarity in the distribution, is the large proportion of the population supplied gratuitously, by means of self-closing public conduits (Fig. 2). The design of these appliances was, therefore, the subject of much consideration. The pattern finally adopted can be made to close either with, or against, the water pressure, by simply taking out and reversing the spindle valve; the counter weights admit of being exactly adjusted to the resistance, at the various levels of the town, so as to leave in each case, whether closing with, or against the water-pressure, just so much preponderance as may be found sufficient to close the valves.





The contracts for the reservoir works in Salsette, and for all the pipe-laying, were let to Messrs. Bray and Champney, of Leeds. The pipe contracts were executed by Messrs. D. Y. Stewart and Company, of Glasgow. All the larger sizes of sluice valves, the hydrants, and a portion of the special castings were manufactured by Messrs. Simpson, of the Belgrave Iron Works, Pimlico. The sluice valves, 32 inches in diameter, are admirable specimens of workmanship. The valve is made in two segments, the smaller one being about one-fourth the area of the larger. By this arrangement, the valves are rendered capable of being closed or open under the severest pressure, with a very trifling exertion of force. The smaller valves are on Underhay's system, which possesses the advantage of allowing the valve seat, as well as the valve itself to be removed for the purpose of repair, without disturbing the laying of any portion of the mains. The water is delivered at Bombay under a pressure varying from 165 feet to 180 feet.

The conditions under which the work had to be executed were somewhat peculiar. The want of water was so grievously felt at Bombay, that the Government and the public were impatient for the immediate completion of the works. But all the pipes and machinery had to be manufactured at a distance of 15,000 miles from Bombay, and it was a difficult matter to provide shipping to a single port, for so large an amount of dead weight, within so short an interval. Moreover, it was only during the eight months of the fair season, from the 1st of October to the 1st of June, that work could be carried on to any extent in the interior of Salsette. During October and November, while the ground was drying up after the rains, jungle fever of an extremely malignant type prevailed in that locality, to an extent to create a very serious impediment to the effective prosecution of any large works. In the high country of Salsette, the rains are too heavy and continuous to allow of any work being carried on while they prevail; and the torrent that often pours down the gorge of the Goper at that season would inevitably sweep away any works for impounding its waters, left in an incomplete state when the rains set in, unless some provisional outlets were provided for its escape in some other direction.

It was evident, that during the first fair season, the operations could not be sufficiently extended to allow of the completion of the impounding works to the height of the intended waste weir, before the setting in of the ensuing rains. The excavation for the foundations for the puddle walls of the main dam had to be carried through from 15 feet to 25 feet of extremely hard basalt, full of fissures, before it could reach the impermeable rock below. And as the bed of the Goper contained water up to the middle of February, and the rock immediately below the surface, in the gorge that drains the basin of the Goper, was permeated by the infiltration of the entire area of the basin, it was certain that the excavation would be difficult, and that a great deal of water would have to be encountered. These difficulties limited the height to which the dam could be raised before the rains set in; and it was, therefore, necessary to provide a temporary escape-weir, by keeping open the existing gap in the enceinte of the basin, which it was ultimately intended to close by Dam No. 2. As the water could not escape by this outlet until it had reached the 56-feet contour, it was essential that Dams No. 1 and No. 3 should be carried to a safe height above this contour before the setting in of the rains. It was, therefore, stipulated by the Author, in the specifications and the contract deed, that during the first fair season's operations, Dams Nos. 1 and 3 should be raised to the height of the 70-feet contour; the site of Dam No. 2 remaining untouched until after the first rains, to serve as a temporary escape weir. By this plan, the water falling during the first rains occurring after the commencement of the works, were impounded in the reservoir to the height of the 56-feet contour. It was specified that the laying of the conduit pipe should be simultaneously proceeded with, so as to render the water, so impounded during the first monsoon, available to the wants of Bombay during the ensuing dry season, and that by the termination of the second fair season, on the 7th of June 1858, all the works, including the town distribution, should be fully and satisfactorily completed.

These arrangements were in all essential points successfully carried out. The Dams were just completed to the height required to insure safety, before the setting in of the first monsoon; the rain-fall of which first monsoon was thus impounded and stored to the 56-feet contour; and the works will be in a complete state to receive the rains, commencing in June next, by which rain-fall the lake will be filled to the waste weir, and its surface extended over an area of 1,394 acres.

The only contretemps that has occurred, has been occasioned by the difficulty experienced in providing shipping for the pipes with sufficient rapidity, but the effect of this delay will be merely to retard the completion of the detailed distribution in the town to some weeks beyond the specified date, which, as such delay will operate during the rainy season, when water is only too abundant, will be attended by no practical inconvenience.

Much difficulty was experienced in raising the principal dam to the height required to insure safety, before the setting in of the first monsoon, June 1857. The Contractor had arrived at Bombay at the commencement of the fair season of 1856-57, but the locality and the season were so unhealthy, that the works at the reservoir could not be commenced in earnest, before the beginning of December 1856. On the 15th of that month, there were, however, upwards of two thousand men employed in the excavation of the trench for the conduit pipe, and fifteen hundred men and one hundred and seventy carts on the principal dam at Vehar. The excavation for the puddle wall already occasioned much anxiety, from the hardness of the rock and the volume of the surface springs, which were formidable obstacles to the progress of the work. These difficulties increased as the excavation proceeded, until the engine-power employed was barely sufficient to keep down the water. A thoroughly impermeable foundation for the puddle wall was not attained throughout its entire length, until the commencement of March, or very close upon the rainy season; so that the Resident Engineer's bi-monthly progress reports were most anxiously looked for by the Author. All difficulties were, however, surmounted, by the ability of the engineering staff, and by the energy of the Contractor. On the 16th of June the dam had reached the height required to insure safety, although the rains had commenced five days earlier; but that still left a considerable margin for safety, for the rain-fall had to fill the lake to the 56-feet contour before any damage could be occasioned to the dam, and the main-pipe of 41 inches diameter, was all the time discharging a river of no contemptible volume. Notwithstanding this, the rain-fall of two days, the 22nd and 23rd of June, on a gathering-ground of 4,000 acres, sufficed to add one million two hundred thousand gallons to the contents of the reservoir. As soon as the water had attained the level of the 56-feet contour, and escaped freely through the gap in the hills which served as the temporary waste weir, measures were taken for closing the pipe, of 41 inches diameter, and for retaining the water in the reservoir, to meet the requirements of Bombay during the ensuing dry season.

Since the termination of the last rains, the level of the lake has kept up remarkably well, its surface not having lowered more than 6 inches per month. This loss is stated to be principally due to leakage through the temporary plug by which the conical orifice of the pipe 41 inches in diameter is at present closed. No leakage whatever is perceptible through either of the dams. The small amount of this monthly loss proves how inapplicable the result of observatory experiments on evaporation, on a small scale, are to the circumstances of a large body of water, such as that constituting the Vehar Lake.

H. C.

No. CXXVII.

FINANCIAL RESULTS OF MADRAS CANALS.

Memorandum by Lieut.-Colonel. J. C. Anderson, R.E., *from the Report of the Ganges Canal Committee.*

I am quite willing to accept Sir A. Cotton's estimate of the benefits derived from the Godavery and Kistna works. But I am of opinion that these works were carried out under exceptionally favorable circumstances; and that there are few, if any, non-Delta formations in India where the same results could be attained at the same proportional expense. Not only would Government be disappointed were they to take the returns from the Madras Deltas, as the standard which properly managed irrigationed works ought generally to yield, but private companies might be led, through the same mistake, to embark in schemes which a real knowledge of the Delta works would have shown them, could not be of an equally profitable character. In the belief that a description of the peculiar advantages under which the Godavery and Kistna works were executed will not only be useful in clearing away much mis-apprehension that prevails regarding them, but will help the Government to understand better than they seem to do at present, the cause of their yielding a much higher rate of profit than the irrigation works in the North of India, I proceed to impart such information as I possess on the subject.

In the Godavery and Kistna Deltas, irrigation from old channels was carried on to a considerable extent before the new works were commenced. In the reports on the Godavery, frequently allusion is made to the old channels. They are described as being very imperfect, as they opened from the river bank on a high level, which rendered them liable either to get an insufficient supply when the river was low, or an excessive one when it was high. The actual value of the channels however was not only considerable, but they afforded the means of at once distributing the water from the new main channels, and they possessed an agricultural class ready to use it as soon as it was offered them. The new works were thus enabled to return a profit much earlier than they could have done, had an entirely new system of distribution channels formed a part of the project.

That the old channels in question must have been valuable adjuncts to the new works, is shown very clearly in the following extract from Captain Orr's Report. "By what has been shown as the benefit derivable from the anicut by means of the channels immediately affected by it, it will be seen, that with an expenditure of 9 lakhs, an annual increase (calculated on the lowest data) of Rs. 1,09,451 would be obtained, a result of itself sufficient to justify the construction of the anicut."

In the Kistna Delta there were not only irrigation channels of considerable size, but a large number of tanks, both of which have been of invaluable service to the new works. Of the channels I may particularize the Pullairoo in the northern section of the Delta. Though now of moderate size, about 50 feet near the head, it is evidently an ancient arm of the river, running on a ridge like the Kistna itself, and admirably adapted for distributing the water for irrigation. It sufficed by means of numerous small branches to irrigate a large proportion of the Delta; that is when it had water. Before the construction of the anicut at Bezwada, it was liable like the channels in the Godavery, to receive either an insufficient or excessive supply, according as the freshes might be below or above the average, and like them and the channels in Tanjore, it only wanted a regular supply to secure the revenue due to the whole of the land under it. This want, the anicut, combined with a new head 15 miles in length, supplied, and the desired result was at once attained. The importance of this channel and its value to the new system may be understood from the fact, that when 65,000 rupees had been expended in the course of about eight years subsequently to the admission of water from the anicut, solely for clearance and repairs of the channel and its branches, 6,500 rupees only had been expended during the same period in new works and improvements. The cost of repairs to the Delta channels is under 8 annas per acre of irrigated area, and the water-rent was until lately 3 rupees per *acre, or six times as much.* *The large expenditure on repairs therefore* represents a large irrigated area.

Another channel existed in the southern section of the Delta and conveyed water to a number of important tanks to supplement the supply from the local rain-fed streams. A cut of 12 miles in length connected it with the anicut, and changed its supply from a variable and uncertain quantity to a certain and uniform quantity. There were 17 tanks under this channel, and the average revenue derived from them, from 1851 to 1855, that is for four years prior to the introduction of a supply from the anicut, amounted to Rs. 52,929, the minimum being Rs. 31,458, and the maximum Rs. 70,092. The revenue derived from the same tanks in 1863, the last year of which I possess the accounts, was Rs. 1,39,323, showing an increase over the former average of Rs. 86,394. The fluctuation of the revenue before the admission of water from the anicut was very remarkable; thus in the course of four years only, four of the tanks yielded respectively a minimum revenue of Rs. 0, Rs. 10, Rs. 323, and Rs. 123, and a maximum of Rs. 3,321, Rs. 2,908, Rs. 3,663, and Rs. 6,327.

The supply of the tanks was formerly very precarious, and the above examples testify to what extent both Government and the Ryots were liable to suffer. The immediate effect of the more certain supply from the anicut was to give confidence to the Ryots, to secure the revenue at the highest figure to which it could have risen had the tanks received a good supply from rain, and by doing away with all risk of loss to the cultivators, to induce an extension of the cultivation, and a further increase of revenue. But without the aid of the tanks and the channels leading to them, which were, as I may say, superadded *gratis* to the anicut works, the same increase of revenue could not have been attained, except by a large additional expenditure on new channels or tanks, and a delay of several years.

Besides the above, there are another series of tanks in the Kistna Delta which were fed by a number of small channels from the river. A short branch from the new main channel into a cutting which had been formed to make an embankment along the river, fed these tanks with a regular, instead of their former precarious, supply, and a large increase of revenue was the result.

It will thus be seen that the Godavery, and still more the Kistna, Delta works, started in possession of some advantages over an entirely new system of works like the Ganges Canal, where not a single village channel existed along the length and breadth of the country to be irrigated, and where the cultivators were unused to any other mode of irrigation but that by means of wells.

The Godavery and Kistna works have other advantages in regard to the alignment of new channels, which alone would render a comparison between them and the canals in the N. W. Provinces, altogether unfair.

The anicuts which have been constructed across the Godavery and Kistna are about 14 and 19 feet, rsepectively, above the bed, and the ground along the banks may be from 13 to 17 feet above the crest of the anicuts. The heads of the main channels are between 5 and 6 feet lower than the crest, consequently the depth of cutting will be from 18 to 22 or 23 feet. If this depth of cutting had to be maintained for any considerable distance, the expense of conveying the large body of water required for the irrigation of the Delta would be very great. But the fact of the country to be irrigated being liable to periodical inundation by the river from a remote period, implies that the deposits during a series of years have raised the land along the banks to a higher level than that at a distance from them, so that the deep cutting at the head of the main channels works out into a moderate and inexpensive cutting in the course of a few miles.

Sir A. Cotton in one of his early reports on the Godavery, thus describes the peculiarities I have mentioned:—"Besides the slope of the land towards the sea in a Delta, it has another slope, viz., a fall from the river in a direction perpendicular to its course, and the fall is much more rapid than that towards the sea. In the present case it has been ascertained to be, near the head of the Delta, 16 feet in two miles from the west, and 7 feet in two and a half miles on the east side. Thirteen miles lower down, that is twenty-five miles from the sea, the fall is 9 feet in two and a half miles on the west side of the Godavery. Thus the river banks form a ridge from 18 to 7 feet above the level of the land, at the distance of from three-quarters to two and a half miles distant on either side, providing most remarkably for the leading out of the water upon the lands.

"The apparently formidable operation of bringing the water from the bed of the river is, upon an examination of the level, reduced to this, that the highest part of the Delta is only 8 or 10 feet above the bed of the river in its immediate neighbourhood, that is within two miles of it; and that if an anicut be built 11 feet high above the deep channel of the river, the deepest excavation for the irrigating channels will be 18 feet, and that within two miles, the country on the west side would be below the level of the top of the anicut. On the east side the lands would be on the same level within about four miles. The apparent objection arising from the great depth of the river is thus completely disposed of."

On the Ganges Canal the water before reaching the tract of country requiring irrigation, had to be carried across a series of formidable torrents, which required a vast expenditure of time and money. Had the canal been opened from the river below the point where the last of the torrents joins it, it would have had to traverse a distance of 50 or 60 miles before the irrigation limit could be attained. In either case heavy expenditure was necessarily entailed before the water could be turned to any use.

The main channels in the Godavery and Kistna are simple cuttings, unimpeded by any natural difficulties. Combined with the anicuts, these short cuts carry the water to the points from which it may be distributed to every field in advance, to near the sea, and the distribution channels have not to extend beyond an average distance of 30 or 40 miles.

On the Ganges Canal the water is conveyed over much more unfavorable ground to a distance of 350 miles from the head. Sir A. Cotton considers this fact as one of the errors of the original project. The practicability of forming separate heads between Roorkee and Cawnpore in order to reduce the distance to which water is conveyed, without being utilized, forms the subject of separate enquiry. I may remark in this place, that the principal object of the Ganges Canal was to ameliorate a famine, and with this object the water was distributed in a certain proportion over a much larger tract of country than was economically necessary. Had it not been for the restriction thus laid on the projector, he could have utilized the whole of the available supply of water in a canal of one-half or one-third the length to which it has been actually carried, and would have had the opportunity of effecting a large saving in the cost of the work.

There are several other facts which serve to explain in some measure the high and quick returns yielded by the Godavery and Kistna works. There is an enormous extent of waste land in the Deltas; the great mass of it is either sandy or more or less swamp, but large tracts not far removed from the sea, and recently inundated by it, are unfit for cultivation until the soil is improved. Both this and the sandy soil, however, become as valuable as any other land in the Deltas, after several floodings by the river water, loaded as it is with mud of the most fertilizing character.

Large tracts are thus rendered productive, which in their natural state were absolutely useless. A further extent of country is brought within the influence of the Delta channels by embanking or draining swamps. It is a common occurrence for 1,000 or even 2,000 acres of such waste land to be taken up in one plot for rice cultivation in a single season; and there is one instance in the Kistna Delta, of the Ryots of a number of villages uniting to present an agreement, to take up in one block 15,000 acres of waste land as soon as certain drainage and irrigation channels should be completed, and to pay Government rent for it at the rate of Rs. 6 per acre, or Rs. 90,000 in all per annum. This is no exaggeration, as the land was actually taken up on those terms as fast as the drainage and irrigation works progressed.

The canals in the N. W. Provinces have no such advantages. Not only is the area of waste culturable land, in the Doab between the Ganges and Jumna, of comparatively small extent, but the revenue settlement extends over a period of 30 years, and the cultivator has to pay no more for irrigating waste land, than the small water-rate which he has to pay for land already under cultivation.

But on the other hand, high as the returns have been from the Delta works, they would have been far higher had the works experienced a tithe of the liberality with which the Ganges Canal has been treated from first to last. Notwithstanding the Government have received incontestible proofs of great and manifold advantages having accrued, both to themselves and to the country, from the extension of irrigation in the Madras presidency, the works which above all others may be taken as the type of what can be accomplished when a supply of water can be cheaply distributed, are only half finished.

The Government readily sanction the estimates for the various new works and extensions that are submitted to them, but the money to carry them out is not forthcoming. Not even the modest demand of the local officers for a fixed and regular annual allotment of 5 lakhs of rupees per annum for new works on the Godavery and Kistna united, until the Delta system shall have been fully developed, has been complied with. Channels which may have been in progress in one year, are summarily stopped the next; or if the main channels are completed, the funds required to carry out the minor works and to turn the others to profitable account, may not be granted, though the works themselves have received the complete approval of Government. Numerous instances could be adduced in which the delay that has thus arisen in utilizing the supply of water, has occasioned a large loss of revenue. I have described the advantages which the Delta works had at starting over the Ganges Canal, and to render the comparison a fair one, I think myself bound to take conspicuous notice of this one great disadvantage which they have had to contend against for a long succession of years.

Many of the drainage channels in the Godavery and Kistna have been used for carrying the water for irrigation. In the country affected by the Ganges canal the drainage courses are deep, and nothing would be gained by using them as irrigation channels. Had they been shallow, the local Engineers would probably still have avoided them, and would have preferred to go to the expense of excavating new channels rather than interfere with the proper function of the drainages. Allowing that there are serious disadvantages in using channels for both purposes, there can be no doubt that the Engineers in the Godavery and Kistna have secured a large additional revenue by being content to use imperfect channels, when time and money would have been required for the excavation of new ones.

The slight fall of many portions of the Deltas, combined with the system of using the natural channels for purposes of irrigation, serves to produce extensive swamping; notwithstanding this, it as a remarkable fact that the Deltas are more healthy than other parts of the district. Fever especially is far less prevalent in the Deltas than in the country immediately beyond it, where there is but little rice cultivation and no swamps. The cause is unknown to me. It can hardly be the influence of the sea air, because the formation of the east coast of India closely resembles that of other countries which are notoriously unhealthy. It is more likely, I think, to be in the geological formation of the soil. However that may be, it would be useless to attempt to prove that ill-drained rice cultivation in the N. W. Provinces should be healthy, because it is healthy in the Madras coast districts.

There are but few bridges on the Godavery and Kistna canals. In most cases bridges are built over the locks, but on several of the channels there are no bridges for 30 miles and upwards. On the Ganges Canal the bridges are built at every two or three miles apart. They have not been constructed in such profusion, simply because the Engineers thought them necessary or wished to construct them, but because the Local Government, acting as they would act towards a private company, insisted on having them where communications were intersected.

Sir A. Cotton's argument in favor of the procedure which has been followed in Madras seems a sound one. Doubtless, in some parts of the Deltas, considerable inconvenience is occasioned by the want of bridges, but if only a limited sum was available for expenditure, is was best that it should be used to extend the irrigation.

The actual want of bridges is not so great in the Deltas as in the N. W. Provinces, for the nature of the soil and absence of suitable material are almost prohibitory to the formation of roads which should be passable in the rains. Indeed, there are no metalled roads in the Deltas, but the numerous navigable canals supply their place along the principal lines of traffic, and any other traffic is unimportant. In the Ganges and Jumna Doab, there are greater facilities for moving carts; the extent of thickly populated country is much greater; and there is a far higher proportion of important towns and villages, than are to be found in the Godavery and Kistna. Hence, more cross communication is necessary, and we may reasonably expect that bridges at short intervals will be looked upon as a necessary addition to the canals. I may add that the canals in the N. W. Provinces, are rarely closed unless for emergent repairs, when some sacrifice of revenue is likely to be entailed; and that bridges can be built at a considerably less cost in the first instance before water is admitted, than would be possible afterwards.

Thus it appears that a considerable expenditure on account of bridges has to be borne by the Ganges Canal, while the Delta channels in Madras are relieved up to this time of any heavy charge on the same account.

In the Godavery and Kistna channels, navigation and irrigation can be carried on together more favorably than is possible on the canals in the N. W. Provinces. The principal crop in the Deltas is rice, which requires water from July to December. There is also sugar-cane and a second crop of rice in the Godavery, but the area and quantity of water consumed by them is small compared with the requirements of the others. The channels are aligned with a slight fall, generally from 3 to 6 inches a mile, and locks are placed at such intervals as will allow of still water navigation, when the water is not required for irrigation.

The surface fall of the channels does not necessarily correspond with the fall of the bed. For three or four months in the year, July to October, it may be increased to 9 inches per mile. The velocity, especially in the upper reaches, is then very considerable, and boats cannot work up-stream without some difficulty. But for the remaining eight months of the year, a smaller body of water is admitted from the river, and for half that period there is practically still water navigation. On the Ganges Canal, on the other hand, the principal demand for water is not during the rains, when the river could supply any quantity that might be required, but during the dry season. Rice is the great staple produce in the South of India, wheat that in the N. W. Provinces. The one is raised in the rains, the other in the dry season. The wheat crop on the Jumna Canals is greater than all the rain crops united. These canals have been in operation for many years, and rice cultivation has in no way been discouraged, unless near cantonments and large towns; yet it has not extended to such a degree as to require a greater supply of water than the wheat. The following figures which are taken from the last Report (for 1864-65) of the Chief Engineer, Irrigation Department, Punjab, serve to show the state of the Irrigation under the Western Jumna Canals.

Total number of acres irrigated during 1864-65, 434,965.

Area in acres of the principal crops irrigated for the last five years:—

	1860-61. (Famine year.)	1861-62.	1862-63.	1863-64.	1864-65.
Rice, ...	44,965	58,578	57,925	47,353	57,157
Cotton, ...	43,706	33,558	25,549	45,882	77,738
Sugar, ...	26,102	33,782	44,730	30,089	29,786
Wheat, ...	1,81,208	1,48,317	1,11,129	1,45,234	1,63,159
	2,95,971	2,74,235	2,39,333	2,68,558	3,27,840

The rice and cotton are rain, or "Khureef" crops. Wheat, dry weather crop, or "Rubbee:" the sugar is irrigated in both seasons.

The average monthly discharge of the canal was 1,784 cubic feet per second; 243 acres were therefore irrigated in 1864-65 by each cubic foot per second. The following was the discharge during the different months:—

	Khureef.		Rubbee.
May, ...	250	November, ...	2481·8
June, ...	1985·2	December, ...	1717·5
July, ...	2431·80	January, ...	482·72
August, ...	1559·15	February, ...	1532·28
September, ..	2265	March, ...	1898·05
October, ..	2554	April, ...	2554
Average,	1791	Average, ..	1777

From the above it appears that the demand for water in April was as great as in July, and in December and March as in August, though July and August are months in which rice requires a plentiful supply of water.

Instead therefore of the demand for water being fluctuating as is the case in the Delta channels, it is nearly constant throughout the year, and an exceptionally high supply is not wanted owing to the rains; on the contrary, the maximum supply required is that yielded by the river during the dry season, and the current will have to be kept up at its maximum during the whole of the period, which on the Godavery and Kistna is available for still, or nearly still, water navigation.

J. C. A.

No. CXXVIII.

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

(5TH ARTICLE.)

Compiled from the Annual Reports of the Surveyor General of India.
BY H. DUHAN, ESQ., *Personal Assistant to Surveyor General.*

SEASONS, 1859-62.

Kashmir Series.—The operations in Kashmir, under the superintendence of Captain Montgomerie made good progress, notwithstanding the increased difficulties which had to be encountered as the work progressed, and entered higher and more inhospitable ground. In the year 1861, the triangulation was extended over an area of more than 12,000 square miles, including some very elevated and difficult country in Zanskar, Rukshu, the Upper Indus, and in Khagan and Nubra. At several points it was carried up to the Chinese Boundary, and stations were visited in the neighbourhood of the Parang and Baralacha passes, where a junction of secondary points was formed with the North West Himalaya Series, the basis of the Degree sheets recently published in Calcutta by the Surveyor General. The stations in Ladak on the Upper Indus were very high, generally over 17,000 feet. Mr. Johnson took observations at one station more than 20,600 feet high, the greatest altitude yet attained as a station of observation. Several remarkable peaks Trans-Indus, probably forming the watershed between the Chitral and Swat Vallies, were fixed from the stations West of Khagan.

The Topography executed in 1861 comprised an area of about 14,500 square miles executed on the scale of 4 miles to the inch, leaving but a very small portion of Little Thibet unfinished, and completing the greater portion of Nubra, Ladak, Rupshu (or Rukshu) and Yanskar. Several of the Salt Lakes on the Table land of Rukshu were surveyed. Some exceedingly difficult ground was sketched by Captain Austen, in Little Thibet, varying in altitude from 7,000 to 28,300 feet above the sea. The glaciers he has discovered and surveyed are probably the largest in the world out of the Arctic regions, the Baltoro Glacier, in the Braldo branch of the Shigar Valley, being no less than 36 miles long. The Biafoganse is nearly as long, and forms, with the glacier on the Nuggair side, a continuous mass of ice nearly 64 miles in length. To delineate them properly a great amount of roughing and exertion, and not a little danger, had to be undergone by Captain Austen, as it was necessary for him to encamp on them for days, and to ascend to great heights on either side.

The carrying out of these interesting operations has involved vast labor and exposure. The country was found to be barren and desolate in the extreme, and the weather very unfavorable, in consequence of the extraordinary heavy rains, for which the year will probably be long remembered. Contrary to their wont, the clouds crossed over the south of the Himalayas to the Northern side, bringing heavy falls of snow in August, and generally hindering the work. Supplies and firewood had to be carried great distances, argols of yâk dung being often the only fuel available.

The Kashmir party being employed in mountains which are only accessible during the summer months, its field season is the period of recess of the Trigonometrical parties employed in ordinary districts. The usual Survey year commences in October, by which month the computations and maps of the preceding field season are generally brought up, and the party is ready to take the field again. The Kashmir Survey year is exceptional and commences in March. The Officers in charge of the various parties submit their respective annual Reports on the termination of the field operations, which are the real test of the advance made during the year.

The *Coast Series*,* between Calcutta and Madras was placed under

* On the Coast Series in 1860-61, the principal operations consist of 52 triangles, arranged so as to comprise one double and five single polygons, and one quadrilateral. 21 triangles were measured

the Superintendence of Captain Basevi, Bengal Engineers, in the autumn of 1860; the exigencies of the Department having required his transfer from the Trans-Indus Frontier all the way to the Madras Coast. His operations commenced in the vicinity of Vizagapatam, and were proceeding towards Rajahmundry, when on approaching the hill of Kapa in the Rampa estate, he found that his signallers had been driven away from the hill with threats of violence, and that the inhabitants of the District were assembling to prevent him from ascending. The estate is rent free, and the people are a lawless set, though under the control of the Godaveri Magistracy. Captain Basevi, having obtained an extra Military Guard and a body of Police, made his way to the summit of the hill without molestation, and took the necessary observations. One day, the people set fire to the grass on the hill, which was about 8 feet high, and a Rajah brought intelligence that they were collecting to attack the Surveyors; but the fire was extinguished, and the attack was not attempted. Captain Basevi's chief apprehensions were for the signallers whom he had to leave behind at the station, but a guard was left with them, and they were unmolested. The only serious inconvenience occasioned was in having to construct the station on a block of laterite several feet below the hill, for the summit was covered with dense jungle which there was no means of clearing away without the assistance of the villagers, all of whom had absconded. Fortunately, such interruptions are of rare occurrence, only happening in the unusually lawless districts around Hyderabad.

The operations proceeded without further opposition or hindrance, except from the physical difficulties of the ground passed over. The district between the Godavery and Kishna Rivers was crossed, with considerable trouble, owing to the absence of high hills, and the undulating nature of the ground, which was all the more difficult because covered with dense jungle. Thus the selection of stations in such a manner as to form an unbroken chain of quadrilaterals and polygons, became a very tedious and laborious undertaking, involving the repeated rejection of positions which at first promised the requisite visibility in all directions, but were afterwards found to be deficient in some essen-

during the first season, with a 2-foot Theodolite by Barrow, giving a mean triangular error of 0·65″, and an equal number measured the next season, with a similar instrument by Throughton and Simms, gave a mean error of 0·37″. Azimuthal observations on Circumpolar Stars were taken at three stations.

tial relation. Nevertheless, in the two field seasons the principal triangulation was carried a distance of upwards of 180 miles, reaching a point in the Guntoor district near the meridian of Madras, whence it was afterwards connected with the meridional arc between Jubbulpore and Madras, to be extended Southwards into Ceylon.

Great Indus Series.—These important operations were happily completed during the season of 1860-61. Major Walker superintended the triangulation as well as the levelling operations from the sea at Karachí to the Chuch Base Line near Attock, comprising two parties for triangulating the northern and southern sections of the Indus Series respectively, under Lieuts. Basevi and Mr. Keelan; and two parties for the levelling operations. After satisfying himself that the triangulation was proceeding satisfactorily, Major Walker was personally engaged in carrying a line of levels from Masee Pir in Upper Sind to the sea at Karachí, which he accomplished in time to accompany (at the request of the Lieutenant Governor of the Punjab) the expedition under Brigadier General Chamberlain, C.B., against the Mahsood Waziris, and make a survey of the invaded territories with the assistance of Lieuts. Basevi and Branfill.

Sutlej Series.—On the completion of the Indus Series, as above noticed, the Surveyor General decided on carrying an oblique series along the South East Bank of the Sutlej, from Mittunkote to Ferozepore, to tie up the Punjab Meridional series, and form a basis for future triangulation into the deserts of Sind and Rajpootana. Certain small portions of the Indus triangulation which had been executed with a 2-foot theodolite gave unusually large re-entering errors. Lieutenants Herschel and Thuillier, both of the Bengal Engineers, and first Assistants of the G. T. Survey, were consequently sent to revise them with the Great Theodolite, while Mr. Armstrong was selecting Stations and building Towers on the line of the Sutlej. Twenty-one principal triangles were ably and rapidly revised, after which Lieut. Thuillier proceeded to join the Kashmir party, while Lieut. Herschel took in hand the Sutlej Triangulation. This consists of a Series of single triangles, of which one flank rests on the sand hills fringing the Bahawulpore desert, and the other in the lowlands which are periodically inundated by the Sutlej. Thus the greater portion of the rays traverse moist jungles of tamarisk and long grass, alternating with ridges of sand, forming a combination which is peculiarly troublesome in disturbing the atmosphere, and causing lateral refractions to perplex and weary the observer and impair his measures. The principal operations consist of 38 triangles, extending over a distance of 132 miles, from a side of the Indus Series below Mittunkote to the vicinity of Pak Puttun. Being entirely in the plains they cover an area of only 1,960 miles.

Lieutenant Herschel took astronomical observations for the direct determination of azimuth at 9 stations, at an average distance of 72 miles apart. His mean triangular error was 0·53″. In 85 angles his mean probability of error was 0·25, between extremes of 0·10 and 0·38.

Lieutenant Herschel introduced an improvement in the referring marks hitherto used in the Survey. Instead of having two apertures—one for a lamp, the other for a heliotrope—he made both lamp and heliotrope illuminate the same piece of ground glass, the aperture of which was limited by a circular diaphragm, of diameter suitable to the distance. Thus one object is intersected instead of two, and there is no flickering or unsteadiness of signal from wind or imperfect direction of heliotrope; there is no dazzle from too bright a sun, nor total disappearance in its absence, for the mere reflection of the sky suffices to illuminate the glass in tolerably clear weather. One mile is considered the best distance for such a mark.

The *Rahoon Meridional Series*,* under the charge of H. Keelan, Esq., 1st Assistant, G. T. Survey, advanced a distance of 176 miles, by 33 Principal Triangles, arranged in quadrilaterals and hexagons, covering an area of 4,130 square miles. It laid down portions of Jeypoor, Ulwar, Doeli, Boondi, and numerous other places of importance. The published charts of the Kotah and Boondi territories indicate a succession of hills over which it was supposed that the triangulation might have been carried and completed last season. But the ground was found to be the very reverse of what had been expected, and to require the construction of Towers, thereby protracting the operations into another season.

* Mr. Keelan employed Colonel Waugh's 2-foot Theodolite, No. 1, in his triangulation. The average error of his 33 triangles is 0·36″. The mean probability of angular error is 0·30, between extremes of 0·12, and 0·65. Azimuth observations were taken at three stations. The secondary triangulation covers an area of 7,040 square miles.

The *Goorhagurh Meridional Series*,*—under the charge of Geo. Shelverton, Esq., Civil 2nd Assistant, G. T. Survey, traverses a meridian close to that of Umritsur, and was brought to a termination in 1861 by joining the Arumlia Series, which had some years previously been carried by Captain Rivers of the Bombay Engineers, up an adjacent meridian as far as Ajmeer, from the Great Longitudinal triangulation. From Sirsa to Ajmeer it crosses a desert tract, of which Mr. Shelverton reports that, "the main difficulties encountered were scarcity of water, of building material, of laborers and of provisions—the country traversed had suffered for three years from extreme drought; large villages originally containing upwards of 500 families had been deserted by all except first class farmers, who were too proud to work. Wholesome water was scarcely procurable, and water even for building purposes had frequently to be conveyed from distances of 4 and 5 miles. The large reservoirs of water upon which the inhabitants depended for their supply during the greater part of the year had invariably been exhausted, and the expensive kucha wells of the country barely sufficed for local wants. It was therefore under very adverse circumstances that the Goorhagurh Meridional series was conducted during the field season of 1860-61.

During the following season the deserts of Bikaneer, Shekhawati and Marwar were extensively traversed, and a very large area of both principal and secondary triangulation was executed, reflecting much credit on Mr. Shelverton and his Assistants, who skilfully and energetically availed themselves of the facilities offered by mounds and hills, commanding extensive prospects, to fix a large number of positions of importance. In the two seasons the triangulation was carried a direct distance of 342 miles by 50 consecutive triangles, covering an area of 4,454 square miles.

The *Assam Party*, in charge of C. Lane, Esquire, Chief Civil Assistant, was employed in 1860-61, in triangulating along the Eastern Frontier, from the south of Gowhatty to Cherra Poonjee. Recent prohibitions regarding the impressment of coolies occasioned much em-

* Mr. Shelverton employed Colonel Waugh's 2-foot Theodolite, No. 2, in his triangulation. The average error of his 50 triangles is 0·54″. The mean probability of angular error is 0·46 between extremes of 0·18 and 0·87. Azimuth observations were taken at only one station. The secondary triangulation covers an area of 10,954 square miles. Owing to the paucity of good natural or artificial objects, 152 secondary station marks were built for future reference.

barrassment, notwithstanding that the majority of the Cossyahs are porters by trade; delay was thus caused in taking the field, and often afterwards. The operations were further impeded by clouds and mists, and latterly by storms of such severity that on one occasion the whole of the Bunder bazar, on the bank of the Soorma, was utterly destroyed and no vestige left. Final observations were taken for 19 principal triangles arranged in a double series, extending over a direct distance of 62 miles, and covering an area of 1,207 square miles. Eight important snowy peaks of the Bhotan Himalayas were fixed.

During 1861-62, Mr. Lane was absent owing to illness, when his place was ably filled by Mr. W. C. Rossenrode, who extended the triangulation a direct distance of 89 miles eastwards through Cachar towards Munnipoor, and 25 miles southwards towards Independent Tipperah, in all 114 miles by 30 triangles arranged in a double series covering an area of 2,024 square miles. Some of the stations were situated in the Jynteeapore district, but the observations at them were fortunately completed before the rebellion broke out. Reciprocal observations had still to be taken to them from other stations around, necessitating the employment of Hindoostani clashees to work the signals on them; the men, though robbed and threatened, maintained their posts during the rebellion, and only came away when signalled to do so at the termination of the observations.

The *Bombay Party,** under the superintendence of Lieutenant, now Captain, C. T. Haig, Bombay Engineers, 1st Assistant, was engaged in 1860-61 in completing the triangulation necessary to connect the Guzerat longitudinal series, on the parallel of 23°, with the Singi meridional series, which had been brought up from Bombay as far as Surat, by Captain Rivers, some years previously. The connexion was satisfactorily accomplished, notwithstanding that the section of the party

* Astronomical observations for azimuth were taken at two stations. Of the Meridional Series, south of Oodipoor, Captain Haig reports as follows :—" The country through which this series runs is inhabited by the wildest set of savages that I have as yet ever had to do with. The thieves (who form a portion of the inhabitants of every village) for the sake of the clothes a man has on his back, assault him; if he attempts to escape, they bring him down with a shower of arrows, utterly regardless of his life. On this account, communication by messengers was attended with great risk, and consequently Messrs. Da Costa and McGill were each unacquainted with the other's progress until they actually met, otherwise I had intended them to be in frequent communication. It is partly due to this that the Series has a bend in the centre, and partly because the Raja of Saloomber, a very refractory chief, would not permit a Station to be built on his hill, although directed to do so by the Political Agent."

ation was advanced from a side of the Ganjam Series. The area surveyed in detail on the scale of one mile to one inch was 2,320 square miles, and the style of mapping was in advance if any former year. Mr. Nicolson likewise triangulated 2,300 square miles of country.

The *Levelling Operations*,* under Captain Branfill, of the late 5th Bengal European Cavalry, 2nd Assistant, made good progress, having in the two field seasons been carried from a point near Mittunkote, on the Indus line of Levels, to the Dehra Dhoon Base line *viâ* Bahawulpore, Ferozepore, Loodiana, Umballa, and Saharunpoor, and thence on to the Sironjo Base line in Central India, *viâ* Meerut, Allygurh and Gwalior, over a distance of 999 miles. In the course of these operations, stone Bench-marks were fixed at distances of 12 to 15 miles, and the most substantial milestones met with by the road side were also determined, for future reference by Canal or other Engineers engaged in levelling operations. A satisfactory connexion was made with the Ganges, and the Eastern Jumna Canal levels, and those of the Allahabad and Agra Railway, which are now capable of being reduced to the mean sea level as a common datum.

The *Computing Office* in Calcutta, under the Superintendence of Baboo Radanath, chief computer, was engaged in completing the triplicate manuscript volumes of the General Reports of the Parisnath, Hurilong and Chendwar Meridional series, and in furnishing elements for the various Topographical and Revenue Survey parties requiring them. In March last, Baboo Radanath retired on a pension, after 30

* During the course of the levelling operations, it has often been noticed that though the independent results obtained at each station by the respective observers differ if at all by almost imperceptibly minute quantities, the differences have a tendency to go one way, and have occasionally accumulated to large amounts. On this curious and perplexing subject, Captain Branfill reports as follows: "I think we can all subscribe to the following facts—The state of the weather and the season of the year have a very considerable effect on our results, as shown by the difference between observers. We have found that the apparent law of our differences is least developed some time in the middle of the cold season. In a run of bad weather (*i. e.*, bad for the work) the apparent law of our difference is for the most part marked when the atmosphere is clearest, and when we have supposed our observations to be freest from error; and conversely in a run of good weather, when the air is hazy from smoke or dust, or greatly agitated by wind, and in short, when we have found most difficulty in reading the staves, our results have most coincided with each other. Our differences do not appear to vary with the distances of the staves. On the contrary the differences are perhaps even more marked as the day grows older, and the distances of the staves from the instrument are reduced. The general direction in azimuth of the line of our work has some connection with the cumulative differences, and we have noticed that the tendency to differ is more marked when proceeding *towards* a certain point of the compass, than when proceeding *from* that point towards its opposite."

years' service, during which he had repeatedly earned the approbation of the successive Surveyors General under whom he had served. On his resignation it was deemed advisable to remove the computing office from Calcutta to the Head-quarters of the Trigonometrical Survey at Dehra Dhoon, to bring it into more direct connexion with the Superintendent of the Department, and also with the field parties whose computations it has revised and collated.

The *Drawing Office*, under superintendence of W. H. Scott, Esq., Civil Assistant, G. T. Survey, was chiefly employed in compiling Maps of Kashmir and Ladak, from the plane table sheets sent in by Captain Montgomerie. The first of these large maps was transmitted to the Home Government, the second was well advanced. Ten original preliminary charts of the Triangulation in different parts of India were forwarded for the use of the Surveyor General's Office, and duplicates prepared for the Geographer to the Secretary of State for India. Triplicate charts were also constructed for the manuscript volumes of the General Report.

Between the completion of a Survey, in this country, and its publication, a long interval invariably elapses, during which even the Supreme and Local Governments are without access to valuable information, acquired but unimpartible, because of the costliness of manuscript maps and the time occupied in their construction. An attempt was therefore made to employ photography for making rapid copies of maps and charts, as a temporary substitute for the final engravings. This process has of late year been extensively adopted in the Ordnance Survey of Great Britain for reducing maps, as a substitute for the pentagraph, and two complete sets of photographic apparatus were sent out to this country by the Secretary of State for India, for similar employment. The operation was by no means easy, for the apparatus had to be specially adapted to make full scale copies, and not reductions merely, for which it was originally intended, and the maps required to be drawn with special reference to future copying or reducing by photography. An ordinary finished map cannot be reduced without a large portion of the names becoming too microscopic to be easily legible. In the first Kashmir Map the rivers were colored in blue, and the broken land and low hills in red, the higher ranges being in Indian ink. Consequently a photograph of it would show no rivers, and would invert the depth of shading of the high and low hills, bringing the latter into excessive prominence.

Captain Melville, who has already been mentioned in connexion with the Topographical Survey of Kashmir, attained considerable skill as a photographer, and succeeded in making an excellent reduction to half scale of the second Kashmir Map, before any names were printed on it. The names were afterwards inserted by hand, and were then copied to full scale, and afterwards printed for circulation.

After a continuous service of 32 years, during 17 of which he Superintended this extensive and important Scientific Department, Sir Andrew Waugh retired from the service, concluding his administration with the following remarks :—

"In the progress of the survey in various parts of India, during the period I have commanded the Department, many instances have occurred in which the skill, endurance and resources of my officers have been severely taxed, and in which obstacles—physical, social and climatic—have been overcome, in a style, which if known, would justly entitle those who have been employed in such arduous works, to the applause which is conceded to the highest triumphs of British energy. The almost impassable barriers of the greatest mountain range in the world, covered with perennial snow, have been unable to check the progress of our operations; for the Himalaya has been crossed and recrossed, and our stations planted on peaks never before trodden by the foot of man; the swampy morasses and deadly forests, in several parts of India, have been traversed, and many tracts of hilly country covered by primeval jungles, scarcely inhabited by human beings, and forming almost *terræ incognitæ*, have been covered by our stations. The Little Desert has been crossed by our triangulation, and several chains of great length have been carried across the Runn and its conterminous tracts, uniting among themselves the worst features of the desert and swampy morasses and jungles of other parts of India. All these undertakings have been arduous in the extreme, and have been achieved with small numbers and most inadequate means.

"The accuracy and precision which have characterized the Geodetical operations, the extraordinary excellence of the Levelling, and the beauty and fidelity of the Topographical delineations, are the best criterions of the professional merits of the members of the Survey Department in all its branches; while the compilations in office, the Lithographic publications, the labors of the computers, and the skilful work of the Mathematical Instrument Department, are equally deserving of praise, and render it necessary that I should express my obligations to all who have shared in the work, in the field or office.

"From my subordinates, in every grade, with whom I have been associated, and to whom I am so largely indebted for the success that has rewarded my labors in the Department, I have always received the most willing and able assistance in every branch of the work. Their cheerful enterprize and manly endurance have been conspicuous on every occasion; and a more able, reliable, and loyal body of gentlemen does not exist in Her Majesty's Service in any part of the world."

Sir Andrew Waugh was succeeded by Major (now Lieut.-Colonel) J. T. Walker, R.E., as Superintendent of the Great Trigonometrical Survey, and by Lieut.-Colonel Thullier, R.A., as Surveyor General of India.

NOTE BY EDITOR.

This History, having been brought up to the date of the Surveyor General's Annual Reports, which are now regularly published, and of which that for 1862-63 has already appeared in the 1st Vol. of these papers, will for the present be concluded.

Correspondence.

The Editor acknowledges, with thanks, the receipt of the following papers:—The Aden Tanks—Roads in Coorg—The Hurroo Bridge—Breach of the Coleroon Anicut—Manufacture of Irrigation Pipes—Practical Suggestions in Road-making—River Works on the Gogra—Karwar Harbour Works—Waterway of the Sye Bridge.

IRON TIE-BARS FOR ROOFS.

To the Editor.

Dear Sir,—Could you find room in your next issue for the following remarks in reply to J. H. P.'s letter in No. 10.

1. It does not seem to me to be singular that the value $\theta = 0$, should give the maximum horizontal thrust. It merely shows that the horizontal thrust, expressed as a function of the variable θ, is a maximum when $\theta = 0$; or in other language, that the point of rupture is at the crown.

2. I do not take friction into account any more than J. H. P. does cohesion. It follows necessarily from this, that the resultant of the two forces applied to the half arch (its own weight and the horizontal thrust) must act at right angles to the joint. For if it did not, the resultant could be resolved into two forces—one acting in the direction of the tangent would be supported by the reaction of the joint; the other parallel to the joint, unless counteracted by friction (which I do not take into consideration), would cause the failure of the arch by sliding along the polished voussoir.

3. Rankine (Applied Mechanics, page 204) determines the horizontal thrust exactly as I have done. He says: "*when the point of rupture is the crown of the arch . . . . . . it has already been shown that . . . .*

$$H_0 = p_0 \, . \, r_0 \, .$$

p_0 . *being the intensity of the vertical load, and* r_0 *the radius of curvature.*"

I obtain the same result by finding the value of the resulting vanishing fraction. But the principle is exactly the same; and if Rankine is wrong, I am quite content to be wrong also.

4. J. H. P.'s Formula (although no doubt perfectly correct on the supposition that the arch turns on the edges of the voussoirs) is quite inapplicable in practice, from the enormous labor of calculation it entails. Petit has calculated Tables for J. H. P.'s formula, by means of which I have been able to compare his results with mine; and in every case my formula gives the safer result. These Tables of Petit are now very scarce, and without them J. H. P.'s formula is useless.

5. My formula is as mathematically correct as J. H. P.'s; and has the great advantage of giving a safer result, and of being readily applicable in practice.

6. Should you wish it,* I can give you a comparative statement of the results of the two formulæ, as applied to roofs as usually constructed.

Yours truly,

A.

CAMP, BAGNEE,
1st May, 1866.

The above was accidentally delayed in transit.—[ED.]

THE "COMPTAGE AMBULANT."

SIR,—Your correspondent, in the last number of Professional Papers, is perfectly right.

The mistake, a clerical error, occurs in putting the formula $C = O + M' - M''$ into words.

When printing the errata to this volume, will you kindly enter at page 69, line 5; *read*, "That when the traffic is the same up and down the road, it is equal to the number of carts met by the observer going in his opposite direction, added to the number which pass him going in the same direction and diminished by the number of carts going in the same direction which he passes:" *instead of*, "That when the traffic is the same up and down the road, it is equal to the number of carts met by the observer going in his opposite direction, added to the number he passes going in the same direction, and diminished by the number of carts going in the same direction which pass him.

W. J. L.'s letter affords numerical proof of the correctness of the formula.

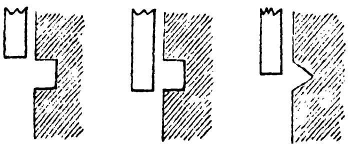
Yours faithfully,

A. J. HUGHES.

HIMALAYA CLUB,
June, 1866.

NOTES ON LEVELLING.

DEAR SIR,—K. C. L. in his excellent remarks on Levelling and Bench-marks in your February number, recommends the broad arrow and bar used by the Ordnance Survey, but he does not state what portion of the



horizontal bar forms the bench-mark. The groove or bar is perhaps half an inch to an inch wide, and the marginal sketches show that there are three distinct positions in which the bottom of the staff may be held, making a considerable difference in its level. It would therefore add much to the value of K. C. L.'s paper if he would clear up the point.

Yours truly,

W. H. M.

8th May, 1866.

* Yes; let us have it.—[ED.]

A SUGGESTION.

MY DEAR SIR,—There are few men in the P. W. Department who have not, at some time or other, suffered in taking over a new division, from the difficulty of finding out the previous history of the large works which have been some time in hand. The relieved officer's Memo. of works in hand is seldom of much use, except for just the current arrangements.

In my own case, I have just taken over a division in which there are several heavy works, about which correspondence has been going on for very many years, and actual work some five or six years. Alterations have been now and again ordered, and many revised estimates submitted, and generally each work has been carried on on the *coming* estimate, so that no one specification has been followed throughout. Just lately some peculiar departures from my specification have come to light, and down comes Government and calls out, who did this, and why did he do it? Now, to make myself acquainted with the works, and answer such questions as the above, I have to hunt up correspondence and progress reports for many years, and then I can't do it. I shall leave the division again soon, and my successor will have all the trouble over again.

Now all this trouble and confusion might be remedied, and also any unauthorised departure from sanctioned specification much checked, if every Executive Engineer had to k[illegible] running note or precis of all correspondence on all large works separate [illegible], in something like the accompanying form.

ABSTRACT OF CORRESPONDENCE, &c., ON____________

Letters received and despatched.				Abstract of Contents.	Contemporary memo. of state of work, orders issued, accidents, &c., &c.
Date.	No.	From	To		

The posting up should be done, I think, by the Executive Engineer himself, and he should enter a work in the book when it had been six months, say, under discussion, posting up the back six months at once.

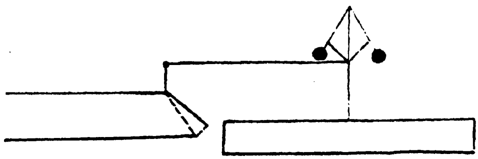
I think the advantage of such a record to every one concerned, will be readily allowed, and I don't think the labor would be a heavy addition to any one. Superintending Engineers would for their own interest see that it was kept up, and each Executive might feel that others were doing the same, so that he would get the benefit when he exchanged. Perhaps some of your correspondents might improve on my idea, and suggest how it could be brought into practice.

Yours sincerely,

A. M. B.

To the Editor.

SIR,—An idea struck me a day or two ago that a uniform discharge, through a pipe with varying heads of water, might be obtained by means of a small water-wheel (driven by the water as it issues through the valve), driving a governor exactly the same as a steam engine governor



so that the lower the velocity of the water the larger the orifice would be, and the greater the velocity the smaller the orifice. Will you favor me with your opinion as to whether it would be of any practical value or not ?

Your obedient servant,

H. H.

Make up a model and try it. The difficulty attending the solution of this problem lies in the practical working : simplicity of construction is a *sine quâ non.*—[ED.]

Correspondence.

THE Editor acknowledges, with thanks, the receipt of the following papers:—The Drainage of Madras—Improvement of River Navigation—Public Works in Berar—Breach of the Krishna Anicut—Church at Steamer Point, Aden—Lakh Irrigation Project—Poona and Kirkee Water-Supply—Irrigation in the South Mahratta Country.

A SUGGESTION.

DEAR SIR,—In reading a suggestion by A. M. B. in the correspondence attached to the last number of the Professional Papers, it struck me that it would be preferable to bind the Correspondence with the Estimates in blank covers.

It seldom happens that large works are carried out as originally designed and estimated; and the advantage of this system is, that an officer carrying out a large work, has all the most important correspondence from the beginning up to date, and there is no necessity for referring to "files" for a letter required to serve a particular purpose. I would only bind such letters as convey suggestions for deviating from the original plans and specification, reports on unusual occurrences, or difficulties in carrying on the works, revised estimates, and the orders received from Government. A note in the column "remarks," in the abstracts of letters "received and despatched" would at once show where the letters missed from their proper places in the "files," are to be found.

I am now doing this for my own convenience, and if relieved before the work I have in hand is finished, the relieving officer will have everything at his finger ends.

CAMP, KOTE,
15th September, 1866.

A. C. C.

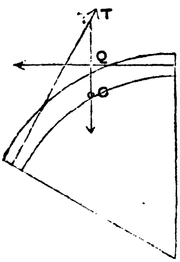
IRON TIE-BARS FOR ROOFS.

SIR,—Being much interested in the discussion which has arisen regarding tie-bars for roofs, on account of its relation to my theory of arches, I beg to offer a few remarks on the subject.

Your correspondent "A" appears to have fallen into a serious error, in regarding the horizontal thrust of such arched roofs as a variable quantity. It ought not to be necessary to prove that this is a constant, but that there may be no doubt I quote from Rankine, "The principles * * * are applicable to linear arches under *vertical loads;* and in such arches, the quantity denoted by H in the formulæ is a *constant thrust*, in a direction perpendicular to that of the load." [*Civil Engineering*, 1864, p. 203.] But "A" must regard it as a variable force, because he says, "there must be some point at which the expression P cot θ is a maximum," and this is the value which he gives for H, or the horizontal thrust [*Professional Papers*, November, 1865.] He makes this statement, apparently, on account of the variable factor cot θ, and accordingly he finds the maximum value of H when $\theta = 0$, and cot $\theta = \infty$. But the necessity that P cot θ should have a maximum value does not exist, for P is also variable; and the product of two variables may be a constant, as for instance $xy = a^2$. And this is exactly what would occur in an arch built according to my theory, and not intended to carry any moving load.

But the arch on which "A" reasons is not so designed, for it is assumed to be of equal thickness throughout. I shall therefore proceed to show, that in this case also, we may not infer that the horizontal thrust must have a maximum value. For the expression H = cot θ is true of one case only, viz. that in which the line of pressure is a circle, concentric with the arch. And if the thickness of the arch be uniform, the line of pressure is not a circle, but a line of varying curvature, to which the formula does not apply, unless we measure the angle θ at the centre of curvature, which is very different from the centre of the arch.

"A" has also fallen into another error, in regard to the three forces by which the semi-arch is held in position. He knows that one is vertical, and another horizontal, and he assumes that the third is at right angles to the joint under consideration. But he over-looks the fact, that three such forces in an arch of uniform thickness would not produce equilibrium at all, for which it is necessary that one must be equal and opposite to the resultant of the other two. This is noticed by "J. H. P." in his letter [*Professional Papers*, February, 1866.] "As there is equilibrium, the direction of this force T must pass through Q."



The way in which I should apply my theory, to determine the strain on the tie-bar is as follows:—

I know that when the line of pressure is a circle, the horizontal thrust is ten times the weight of a portion of the structure at the crown of the arch, the length of which is $\frac{1}{10}$ of the radius of the line of pressure. For in Table III. *Professional Papers*, Aug. 1, 1866, which is perfectly general in its application, making R = 1 and H = 0·1, I found Pm = 0·0050 where Pm was half the weight of the vertical block of the crown. Therefore $H = 10\left(\frac{1}{10}R \times z \times w\right) = Rzw$, where R = radius of Line of Pressure. Then asuming that the Line of Pressure is a circle passing through the middle of the arch-ring, I get $R = r \times \frac{z}{2}$; and therefore $H = \frac{w}{2}[2rz + z^2]$ which is "A's" formula. Lastly, because I know that the Line of Pressure is not really a circle, I should enquire whether the value thus obtained be more or less than the true horizontal thrust. And because it would become a circle by adding weight on the haunches, which would increase the horizontal thrust, I find that the calculated value is *greater* than the actual, and may be used with confidence to determine the strength of tie-bar.

The formula H = P cot θ is perfectly correct for an arch theoretically balanced; in which the Line of Pressure is a circle, concentric with the arch. And for any small arc near the crown, the weight is the same whether the arch be theoretically balanced or not. Hence "A" gets a correct value, from the arch of equal thickness, by taking $\theta =$ an infinitesimally small arc, and I get practically the same, from the theoretically balanced arch, by taking sin $\theta = \frac{1}{10}$ R, (where $\theta = 5^\circ 44'$). But the value which we thus obtain for H is strictly true only of an arch theoretically balanced, and is not strictly true of an arch of equal thickness throughout.

I observe that your correspondent "A. J. H." (in the issue of May), writing on this subject says: "The point of maximum thrust, or joint of rupture is 12¼ degrees above springing level—this is where "A" should put his tie-rods, and up to this point he must build his backing." But the tie-rods are not introduced for the purpose of preventing the *arch* from changing its shape. This is certain, because if the abutments were immoveable, tie-rods would be unnecessary. They are required to prevent the *abutments* from moving, these being only thin walls, wanting in stability sufficient to resist the horizontal thrust of the arch. Therefore the tie-rods must be put at the level of springing, and nowhere else, to be used to the best advantage. If they were placed 12¼ degrees above this, they would afford no security against the failure of the roof.

ALEXANDER H. MACNAIR.

20th August, 1866.