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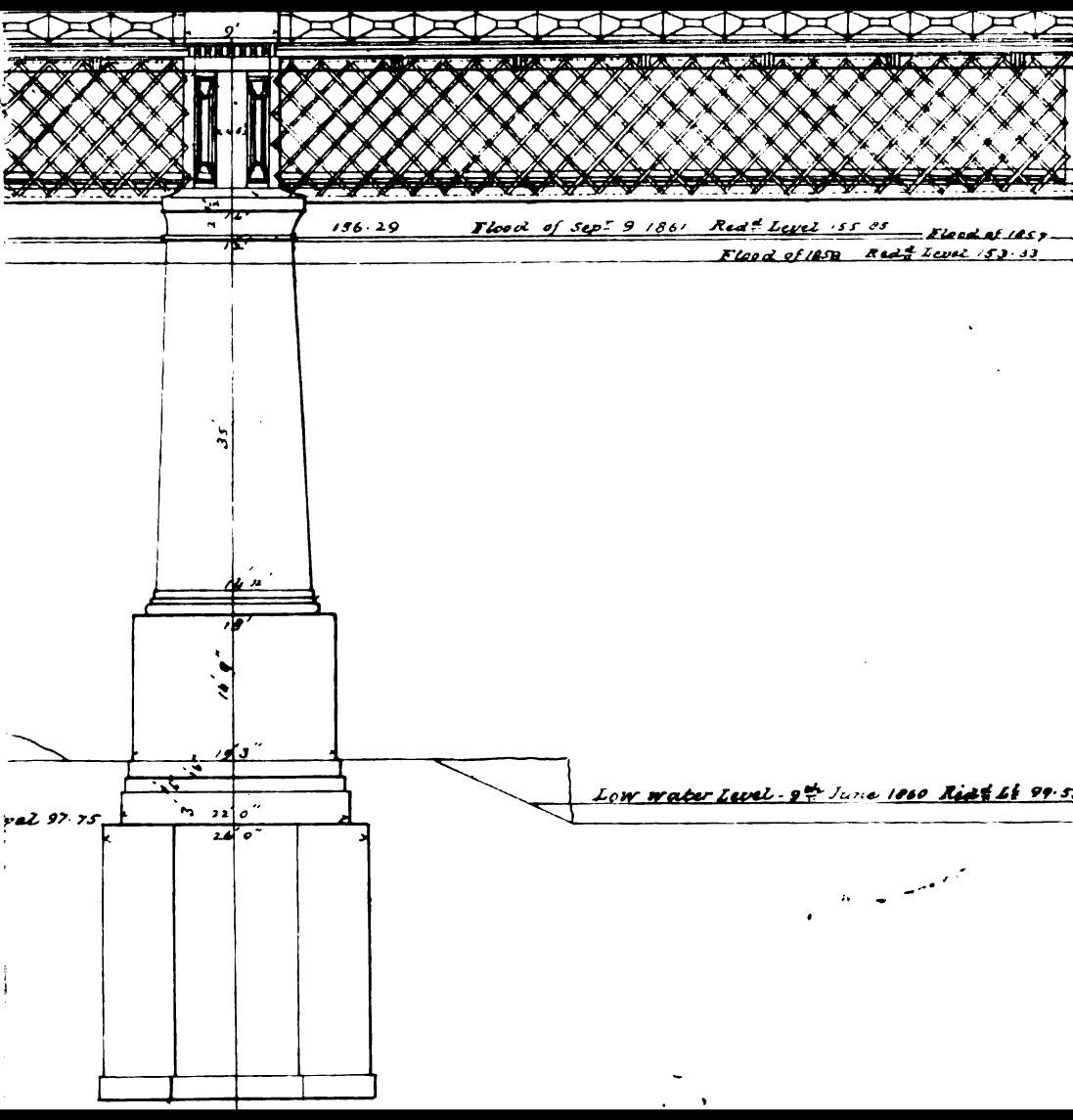

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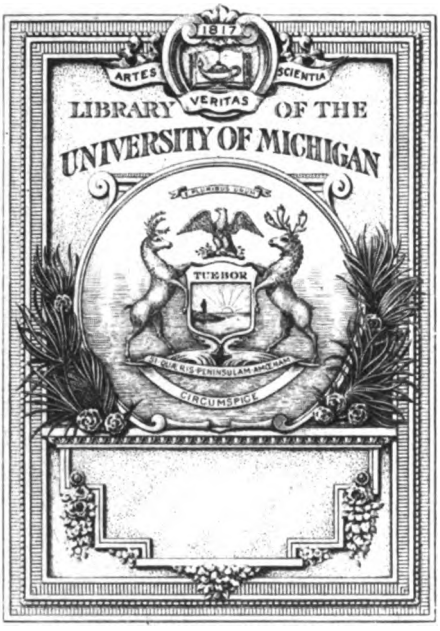

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PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING.

VOL. III.—1866.

EDITED BY

MAJOR J. G. MEDLEY, R.E., Assoc. Inst. C.E.,

PRINCIPAL, THOMASON C. E. COLLEGE, ROORKEE.

ROORKEE:

PRINTED AND PUBLISHED AT THE THOMASON COLLEGE PRESS.

CALCUTTA: THACKER, SPINK & Co. BOMBAY: THACKER, VINING & Co.

MADRAS: GANTZ, BROTHERS. LONDON: SMITH, ELDER & Co.

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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. M.

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THE TONSE BRIDGE.—E. I. RAILWAY.

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* Abstract of Proceedings of the Bombay Government.

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THE POONA CONFERENCE.*

In August 1864, a Public Works' Conference was held at Poona, which appears not to have been the first of its kind. It was attended by a large number of Executive Engineers, and the Collectors of the neighbouring districts, and its objects are declared to have been to show "what has been done during the past season? What is doing this season? What is proposed for future seasons? And how are funds to be provided, with a view to the preparation of the Budget for 1865-66." Such information being furnished under the several heads of "Irrigation Works—Harbour Works—Reclamations—Military Works—and Bridges of various kinds."

The information given in the printed abstract, however, refers almost entirely to Roads, of which it appears that the Bombay presidency is singularly deficient, more than *two millions sterling* being estimated as required to complete the several lines, nearly all of which are stated to be Imperial. The occasion is perhaps a good one to draw attention to the necessity of extending the operations of Local Funds, with a view of providing the country generally with a proper system of internal communications, and at the same time of seeing that the large sums annually granted by Government, are expended in the most advantageous manner. The main Lines of Railway now approaching completion, have proved too expensive of construction and working, and too poor an investment of capital to allow us to hope that they will be supplemented by

* Abstract of Proceedings at the Conference held at Poona in 1864. Printed for the Bombay Government.

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minor lines except in particular localities, for many years to come. At any rate there is little doubt that a very great development of the present Traffic must first take place by means of ordinary roads before these will be superseded by Railways. Now, a very large proportion of such roads, though doubtless of Imperial importance in the eyes of the local authorities, are strictly Local, and in other countries would be made from local funds; while it is almost impossible for the Central Government to balance the respective advantages of the numerous claimants on its attention. One consequence of this is, that money is distributed to all, but necessarily in such small sums that few of these roads are ever completed. A certain stage is reached; the road is lined out, the earthwork completed and culverts built, and then all the money that can be yearly granted, is barely sufficient to keep in tolerable repair what has been done; the large streams remain unbridged and the road is unmetalled, and an unmetalled and unbridged road is to all intents and purposes no road at all. If the Imperial Funds were limited to strictly Imperial lines, there would be some chance of these being finished, and all others should be provided for either by Local taxation or by Tolls directly levied on those who use them.

It is said that the Turnpikes established on the Grand Trunk Road some ten years ago were unpopular, and so is all taxation generally, but it was strictly in accordance with native usage, transit duties being levied by every native Government in the East. It was also said that in many instances the returns from such toll bars did not pay for their cost, as owing to the flatness of the country the traffic was able to escape them. Whatever the reason, the tolls were abolished in these provinces, except on the Boat Bridges over the great Rivers. In Bengal, however, there is still a toll-bar at Sherghotty on the Trunk Road, and others on the District roads, which in 1863-64 produced a (net?) return of Rs. 76,110, besides more than three and a half lakhs net from the Ferry Fund collections. There certainly seems no good reason why tolls on Roads should be more objectionable than Bridge tolls, and the latter are in force at every bridge-of-boats throughout the country. Now, if you make a

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cart pay for crossing a rickety boat-bridge, you have *à fortiori* a right to make it pay for crossing a good permanent bridge; and if the turnpikes were established at proper distances on the *bridges*, some at least objections to them might be thought to cease.

Nor would there seem any insuperable obstacle to allowing roads and bridges to be made by joint stock companies, privileged to exact certain fixed tolls, or else to create Local Road Trusts by district taxation. Every ton of goods carried (at least by Government) on a kucha road could afford to pay two annas per mile if carried on a metalled road instead (*see* Vol. I. p. 303); and even if this rate has to be diminished for private traffic, I believe there are a very large number of district roads with traffic sufficient to afford a handsome return by the levy of tolls.* Thus the traffic over the Delhi bridge-of-boats, according to returns lately published for three unfavorable months of the year, exceeds 10,000 tons yearly; and one anna a ton on this per mile would represent a capital of Rs. 12,000 on every mile of road leading to it over which such Traffic runs, considerably more than would be required to make such a road. No doubt all such taxes upon traffic are objectionable as tending to check its development, but if ever a tax were justifiable, it is surely when it is at once expended on the direct advantage of the district where it is raised. That the wealth of the country has immensely increased within the last few years is admitted by all; the capital spent in the country by the construction of Railways and the expenditure consequent on the larger European force now maintained would make us infer this, even if it were not proved by the great rise in prices all over the country. The money is therefore *here*, and Imperial taxation seems to be at fault as to the mode of getting at it. Why not try the extension of local taxation, thus relieving the Central Government of much troublesome supervision and not a little anxiety? Time was when Local Works were rather

* The strength of a road, like that of a beam, is only that of its weakest part, and if one sandy river is left unbridged through which extra power is required to drag the carriage, the same draught power must practically be kept up for a large portion of the traffic as if *all* the road were sandy; so that a metalled road while *incomplete* saves practically little or nothing to the private carrier.

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a by-word, and much money was wasted by District officers who were amateur Engineers, when each was anxious only to show more miles of kucha roads opened out yearly than his neighbours, and when the cold weather tour of the Lieutenant Governor had at least one good, that the whole population of the district was impressed to extemporize bridges and make the roads passable for His Honor's carriage. Much of that is passed away however; local funds are expended under professional supervision; there is little doubt that they go much further than imperial grants, and it is only a pity that they cannot be doubled or trebled in amount.

Among other subjects discussed at the Conference, a memorandum was submitted by Captain St. C. Wilkins, R.E., on the Subordinate Establishment of the Bombay Public Works Department. It appears that the European Overseers are all taken from the Sappers, and without any previous training. The consequence is that they are quite unfitted for their important duties, whether as Builders, Surveyors, or for Office work. The establishment of the new Engineering College at Poonah will probably remedy this, by providing a proper training establishment, but there seems no reason whatever for drawing the students solely from the Sappers. The Roorkee and Madras Colleges are open to the whole army, and the Sappers furnish a very small per centage of the number of men annually trained. The value of this training will I think be testified to, by almost every Officer in charge of works on this side, nor am I aware of a single case of an Overseer having been discharged from the Department on the score of inefficiency, though unfortunately men do succumb to the common temptation of strong drink. Of this fault, however, there are I believe not more (if so many) instances than amongst any similar number of inspectors or foremen drawn from England, while the advantage of the previous military training is felt and acknowledged by all. Captain Wilkins proposes a *special* training for the students; that they should be divided into four classes, viz., Builders, Surveyors, Draughtsmen and Estimators, and should be compelled to make their choice. No doubt the advantage of special training is great, but with limited establishments as in

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India, it would seem desirable that a man should have a more general training than in England. Moreover, it is difficult if not impossible, to train men as practical *builders* at a College, while experience has amply proved that in all the other three branches the same man may acquire a very considerable proficiency.

The same remark applies to the native Subordinates, of whom Captain Wilkins expresses a high opinion, though stating that "the native mind is eminently unpractical." The reason of that, however, simply is that the natives who flock to the Government Colleges to be trained into Sub-Overseers are not the sons of masons, carpenters and blacksmiths, the working classes; but the sons of bunyahs, and others whose pursuits are sedentary rather than active. The native working classes have not as yet appreciated the benefits of education; when they do, I believe the Sub-Overseers trained for the works will show a great improvement over those now sent out, though the training at a College must still be theoretical to a large extent, and practice must be learnt on actual work. Engineering must be on the same footing in this respect as Law, Medicine or indeed any other profession; and there will always be men in each whose native genius can to a great extent dispense with theoretical training, though they are generally the first to lament the want of it.

Such Conferences might perhaps be held occasionally with advantage in other places, as a means of exchanging information, and ensuring joint action, especially in the case of local works under different authorities. Hitherto, in this Presidency, they have been limited to the discussion of particular measures.

J. G. M.

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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

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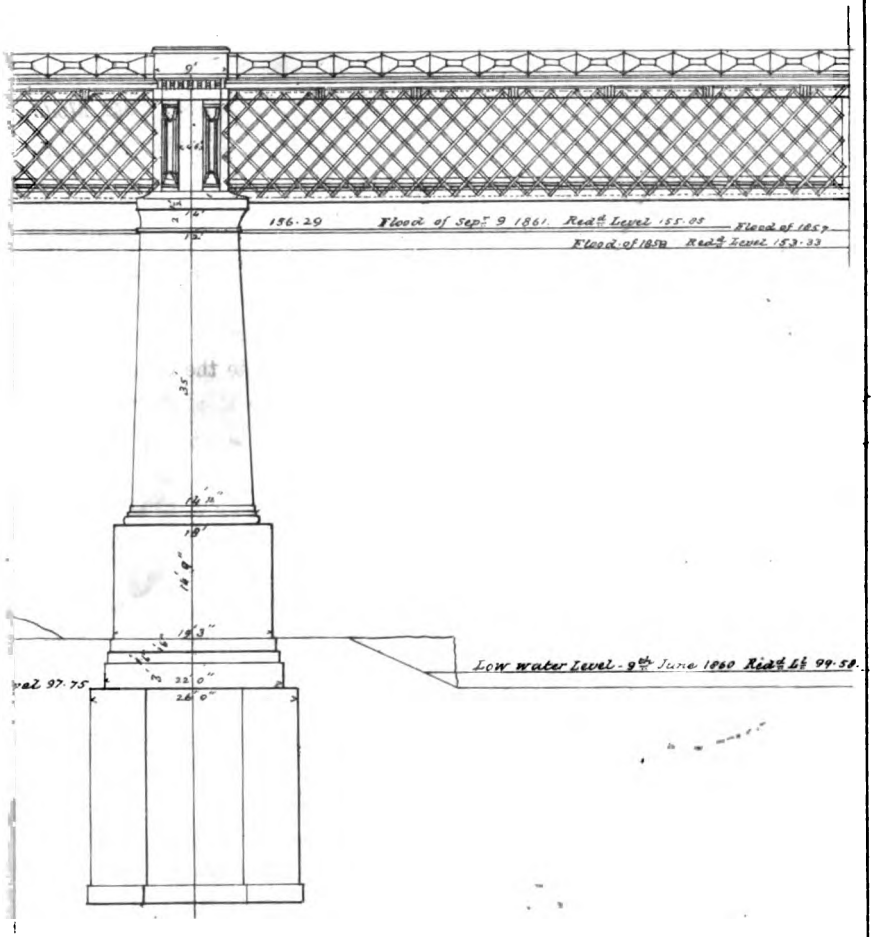
PLATE I.



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of the banks at the site of the bridge, to the lowest point of the bottom of the actual river channel, is about 57 feet, the average depth of the channel being about 49 feet.

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

The height of the water in the rains, however, occasionally reaches 56 feet, and for a great part of the period between July and the middle of September, the surface is above the height due to local floods. This is caused by the water of the Ganges "backing-up" from that river, which it does to a distance of 12 or 14 miles above the bridge; at such seasons the surface is stagnant, and very favorable for some operations connected with bridge building.

The local floods run with a volume of water that occupies the *whole* channel below their surface, so that the waterway is little more than that 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

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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.

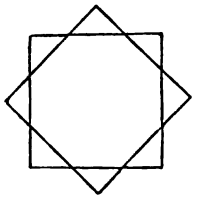
The lattice-girder was selected by Mr. Rendel, the Consulting Engineer to the Company in England, and the ironwork of the bridge, weighing about 1,200 tons, was constructed by the firm of Westwood, Baillie Campbell and Co., of Millwall. The spans adopted were 150 feet, and the thickness of piers was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



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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

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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

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dry. This, however, met with but partial success, and in all cases when the well was dried, it was built up solid.

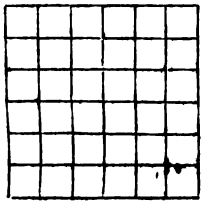
I found this plan, however, uncertain and expensive, and also that the lime set very well under water, which induced use me to fill the wells up solid with concrete; this was composed of—

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 above-mentioned, 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,

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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

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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

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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. 8 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

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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.

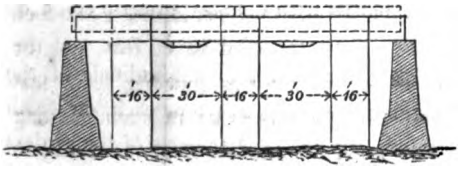
The *Plant* for the whole works, exclusive of brick yard arrangements, consisted of 24 lime kilns; 9 English fashion smiths' forges; a sawpit of English fashion also, and covered in; a carpenters' shop of 95 feet in length; a lime store of about 3,000 square feet area; 3 moulding floors for carpentry 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

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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

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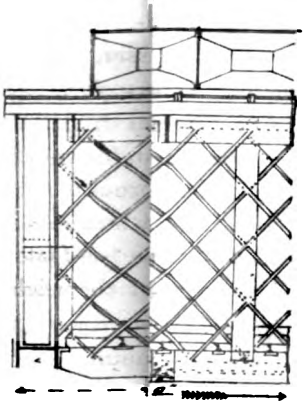
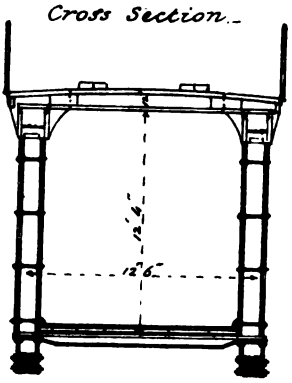
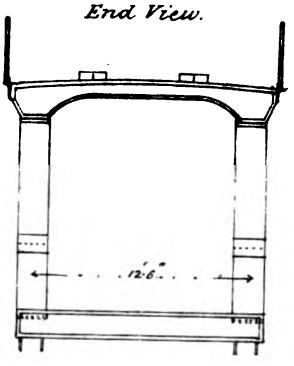


Cross Section.



End View.



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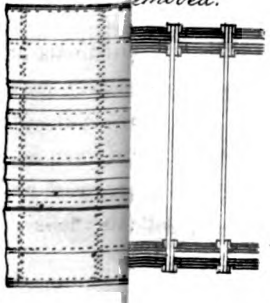
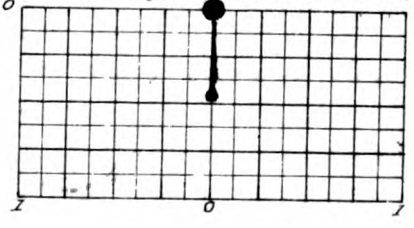


Diagram showing deflection of N° 5 Span of Tonse Bridge, taken during the passage of a train weighing 100 Tons. March 31st 1864.



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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 80 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

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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 transversly 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.

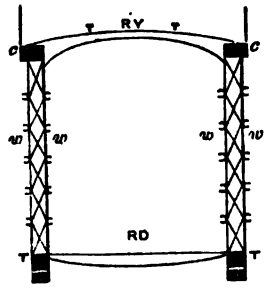
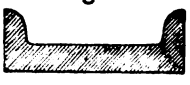


Fig. 5.



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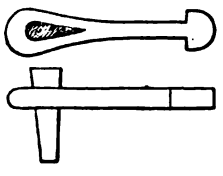
The girders rest on blocks of cast-iron hollowed out underneath, and bolted to the bottoms of the "end standards" or vertical boxes. These blocks rest on "saddles" of cast-iron fixed at one end of the girder, so as to admit of a movement there in a circular or vertical direction only, while at the other 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.



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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 $1\frac{5}{8}$-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 8 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

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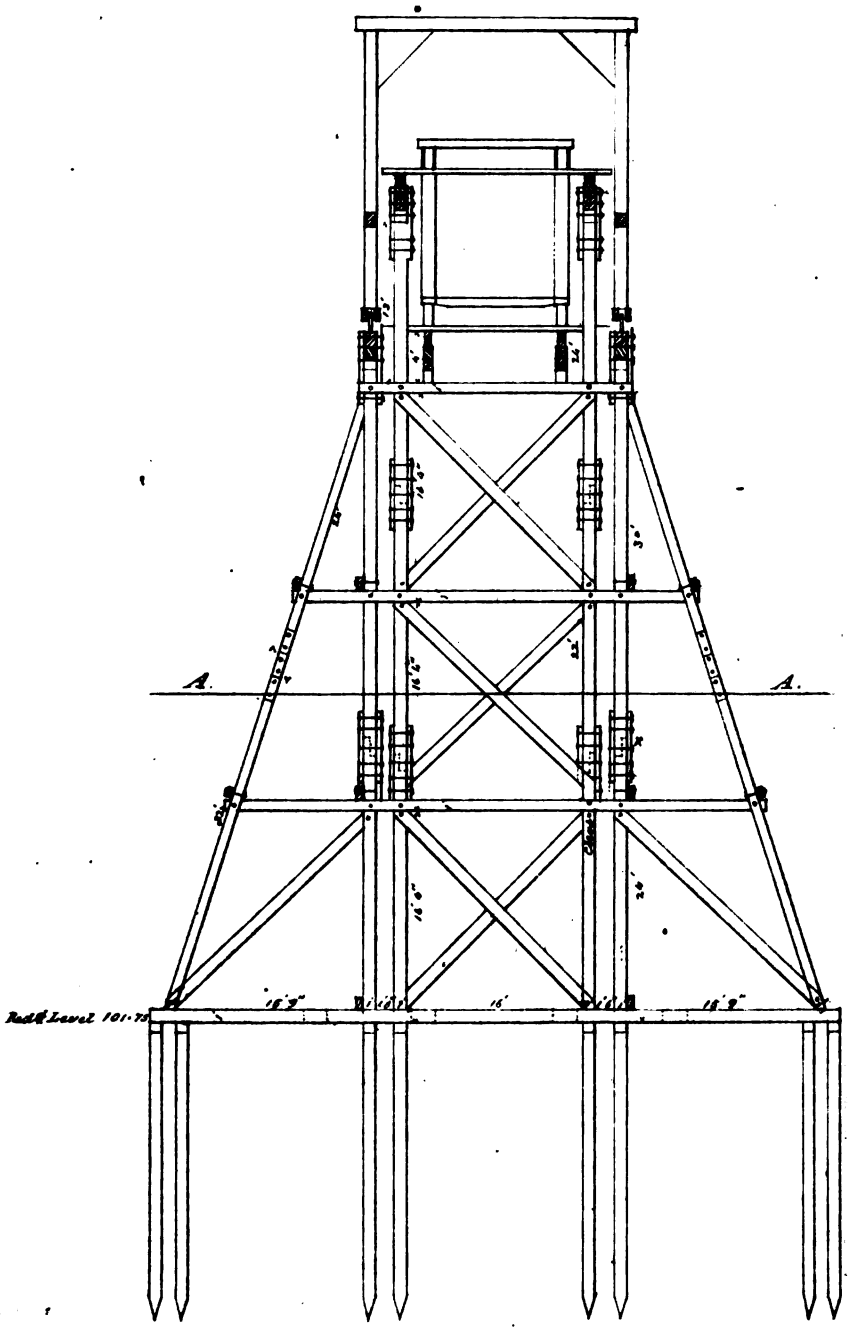
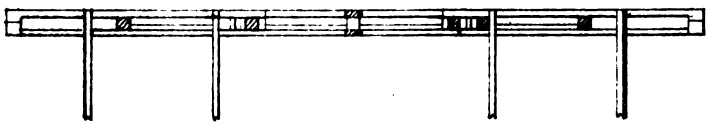
TONSE BRIDGE—E. I. RAILWAY.

Staging used in the erection of the Girders.



Plan at A.A.



LITHO: I.C PRESS.

Scale 24 feet = 1 inch.

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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.

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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 $\frac{2}{16}$-inch, and the side vibration was but $\frac{1}{16}$-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.

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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.

(The photographic view of the bridge, given in the frontispiece, is by Mr. J. Clarke of Allahabad.)—[Ed].

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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

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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

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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 evapora-

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
Rain-fall, ..	0·59	0·62	1·81	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†	..

tion 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

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the effective evaporation of the year, extending over the remaining eight months, is equal to 48·66 inches, or at the rate of $\frac{1}{8}$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

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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 8 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

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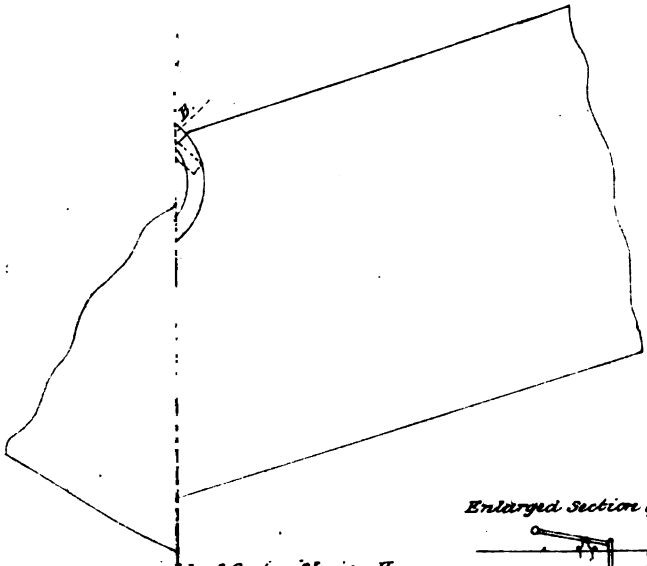
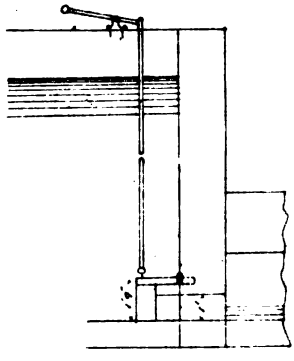
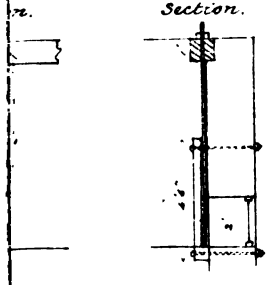


Enlarged Section of Valve G.



Roof Outer Sluice H.



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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

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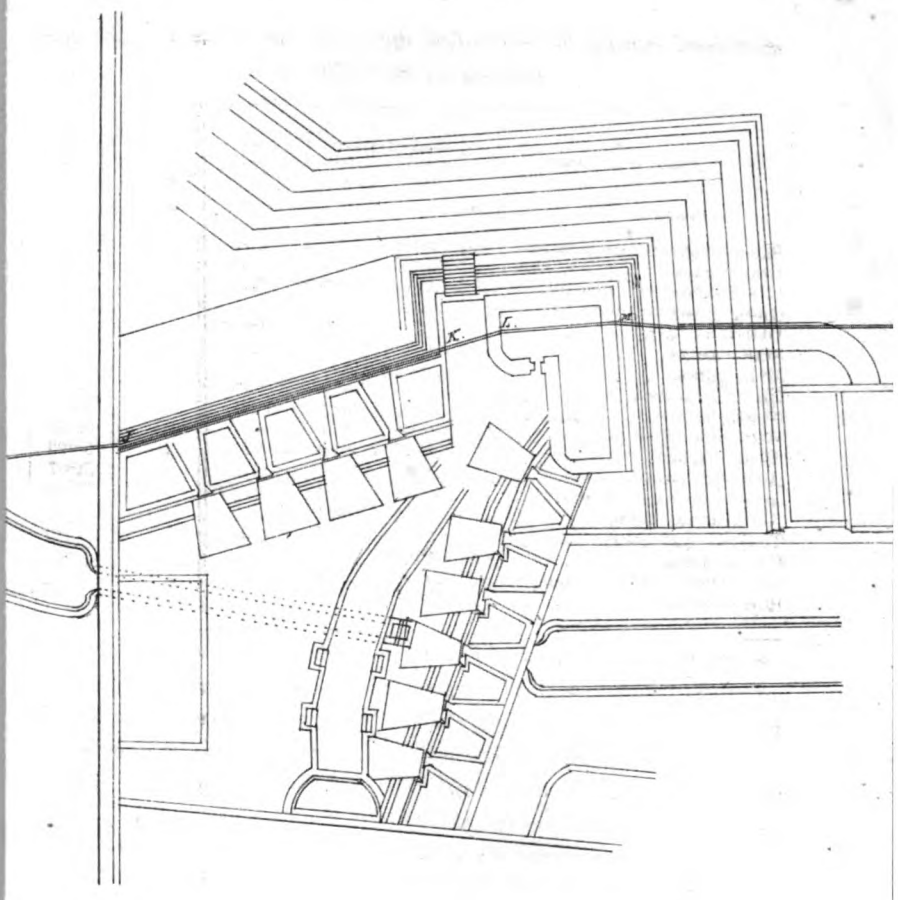

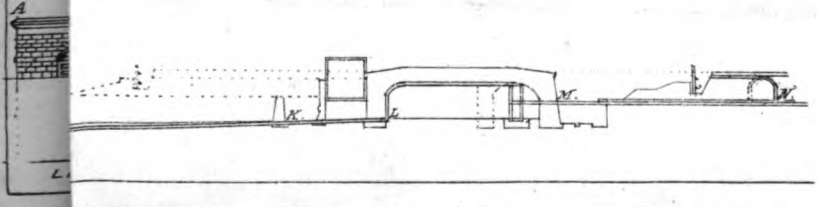

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mains at a higher pressure, so as to fill cisterns on the top stories of the barracks above-mentioned. This will be found shown in the drawing. These high-level cisterns will be filled once a day or oftener if necessary, and the whole system of pipes 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 $\frac{3}{4}$-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 $\frac{5}{8}$ to $\frac{1}{2}$-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.

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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 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

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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.

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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.]

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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

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

Since horizontal members in framing do not transmit vertical forces *directly*, the stresses to produce this vertical pressure on the abutments

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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 thrusts 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 $\theta°$ be the angle the diagonals make with the vertical,

$$T_2 = P_2 \sec \theta°$$

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 $\theta°$.

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 $\theta° = 45°$. The loading is supposed to be on the lower chord or boom.

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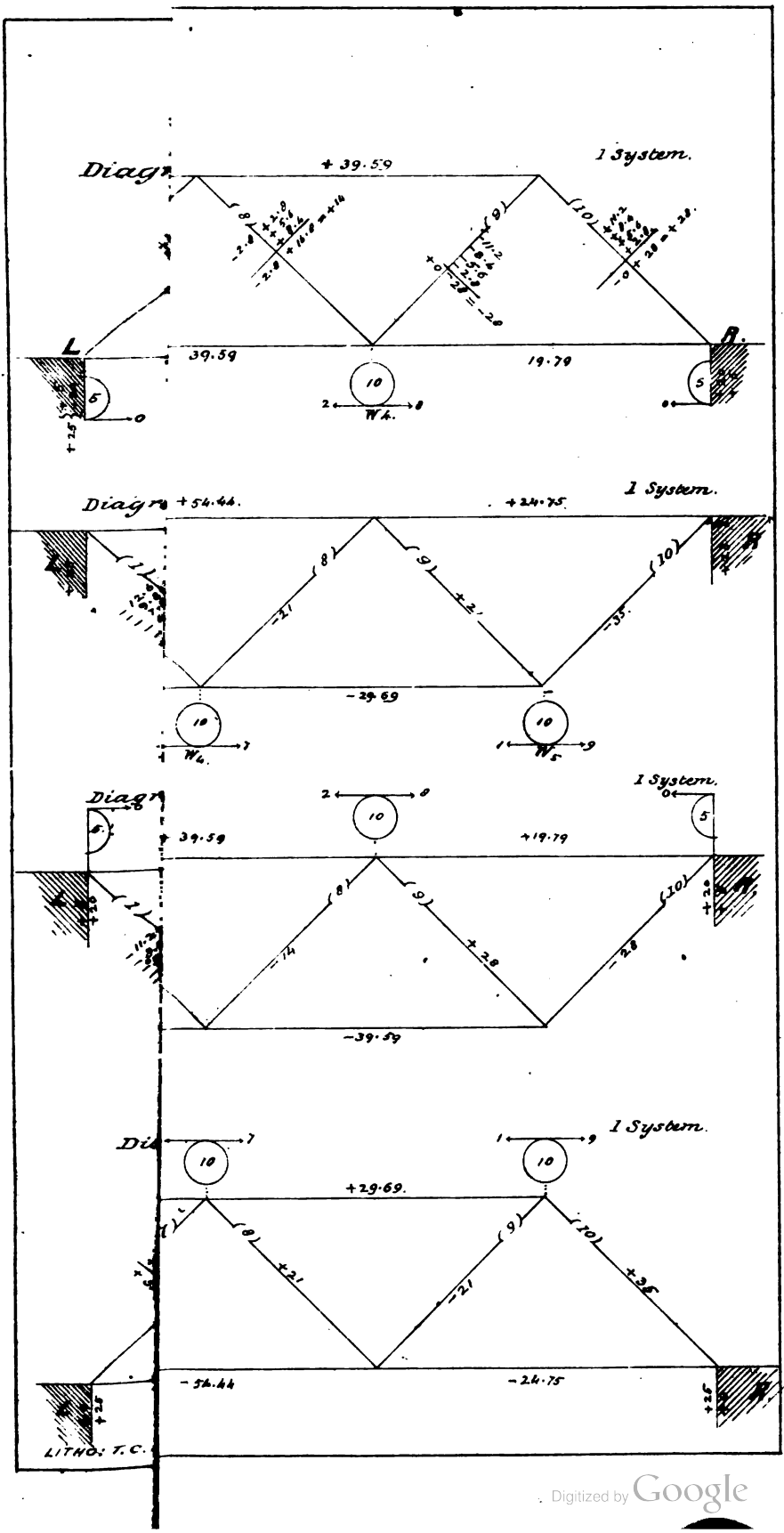

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Beginning with weight W_1, we see it produces a tension on bars 2 and 3, equal $\frac{W_1 \times b\,R}{LR} \sec\theta = \frac{10 \times 40}{50} \times 1{\cdot}4 = 11{\cdot}2$, and $\frac{W_1 \times b\,L}{LR} \sec\theta = \frac{10 \times 10}{50} \times 1{\cdot}4 = 2{\cdot}8$, 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 $\left\{\begin{matrix}1 \text{ and } 2\\ 3 \;\;,, \;\; 4\\ 5 \;\;,, \;\; 6\end{matrix}\right\}$ 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 θ°, thus, for bar 1; $\left.\begin{matrix}+8\\ +6\\ +4\\ +2\end{matrix}\right\} = +20 \times 1{\cdot}4 = +28.$

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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 $ce = cd\ 2 \sin \theta = \dfrac{2\ cd}{\operatorname{cosec} \theta}$.

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*

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the sines of the resulting stresses on all bars, sloping down { to / from } *the centre, which touch the* { top / bottom } *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

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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 θ° : 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.

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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.

$\theta°$, 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.

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T, the *maximum* tension;

C, the *maximum* compression;

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

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

If we examine the stresses in any bar of diagram, No. 1: say the 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: $\frac{W}{S} \sec \theta (L_1 + L_2 +$ &c., $L_4)$; the number of terms in it is of course the number of weights towards one side, which act on the bar through the several "pairs" of the system in which it is. The beam taken as an example being one of a single system, the number of weights is *all* the weights on the beam between the bar and the end; but had the beam been of two systems, the number acting on the bar would have consisted of every second weight; if of three systems, every third weight, and so on. The last term L_4 is the distance of the last weight from the end, *l*, in the notation.

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The sum of the series is therefore in general terms—

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

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—

$\frac{W}{n} \sec \theta \left\{ \Sigma (N - 1) + x + \Sigma (N - 2) + x + \text{&c.}, \right\} x$, 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, $\Sigma = 2\,d$ (para. 13), and—

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

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.

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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* $\left\{ \mp \right\}$ stresses in the bars from end of beam to x, multiplied by $2 \sin \theta = 2 \sin \left\{\begin{matrix} T_R \\ C_R \end{matrix}\right\} \sin \theta$.

(*To be continued.*)

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Weights.	1	2	3	4	5	6	7	8	9	
1	*	*	*	*	*	*	*	*	*	
2			+ 3·33	+ ·18						
3					+ 3·15	+ ·35				
4	− 2·98						+ 2·98	+ 5·53		
5		− 2·80							+ 2·80	−
6			+ 2·63	− 2·63						
7					+ 2·45	− 2·45				
8	− 2·28						+ 2·28	− 2·28		
9		− 2·10							+ 2·10	−
10			+ 1·93	− 1·93						
11					+ 1·75	− 1·75				
12	− 1·58						+ 1·58	− 1·58		
13		− 1·40							+ 1·40	−
14			+ 1·23	− 1·23						
15					+ 1·05	− 1·05				
16	− ·88						+ ·88	− ·88		
17		− ·70							+ ·70	−
18			+ ·53	− ·53						
19					+ ·85	− ·35				
	− ·18						+ ·18	− ·18		
Total, −	7·90	7·00	0·00	6·32	0·00	5·60	0·00	4·92	0·00	
+	0·00	0·00	9·65	·18	8·75	·35	7·90	·53	7·00	
Resulting Strains,	− 7·90	− 7·00	+ 9·65	− 6·14	+ 8·75	− 5·25	+ 7·90	− 4·39	+ 7·00	−

Bars.	TOP BAYS.									
	a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*i.*	
	†	†	†	†	†	†	†	†	†	
1	+ ‡5·60	+ 5·60	+ 5·60	+ 5·60	+ 5·60	+ 5·60	+ 5·60	+ 5·60	+ 5·60	−
2	+ ‡4·95	+ 4·95	+ 4·95	+ 4·95	+ 4·95	+ 4·95	+ 4·95	+ 4·95	+ 4·95	−
4		+ 8·68	+ 8·68	+ 8·68	+ 8·68	+ 8·68	+ 8·68	+ 8·68	+ 8·68	+
6			+ 7·42	+ 7·42	+ 7·42	+ 7·42	+ 7·42	+ 7·42	+ 7·42	+
8				+ 6·21	+ 6·21	+ 6·21	+ 6·21	+ 6·21	+ 6·21	+
10					+ 4·95	+ 4·95	+ 4·95	+ 4·95	+ 4·95	+
12						+ 3·72	+ 3·72	+ 3·72	+ 3·72	+
14							+ 2·47	+ 2·47	+ 2·47	+
16								+ 1·24	+ 1·24	+
18									+ 0·0	+
20										+
Totals,	+ 10·55	+ 19·03	+ 26·45	+ 32·66	+ 37·61	+ 41·33	+ 43·80	+ 45·04	+ 45·04	+

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STRESSES IN DIAGRAM 9.

BARS.

10	11	12	13	14	15	16	17	18	19	20	21	23
*	*	*	*	*	*	*	*	*	*	*	*	*
	− ·18	+ ·18							− 0·18	+ ·18		
			− ·35	+ ·35							− ·35	
+ ·70					− ·53	+ ·53	− ·70	+ ·70				− ·53
	+ 2·63	+ ·88							− ·88	+ ·88		
			+ 2·45	+ 1·05							− 1·05	
− 2·10					+ 2·28	+ 1·23	+ 2·10	+ 1·40				− 1·23
	+ 1·93	− 1·93							+ 1·93	+ 1·58		
			+ 1·75	− 1·75							+ 1·75	
− 1·40					+ 1·58	− 1·58						+ 1·58
	+ 1·23	− 1·23					+ 1·4	− 1·4				
			+ 1·05	− 1·05					+ 1·23	− 1·23		
					+ ·88	− ·88					+ 1·05	+ ·88
− ·70							+ ·70	− ·70				
	+ ·53	− ·53							+ ·53	− ·53		
			+ ·35	− ·35							+ ·35	
					+ ·18	− ·18						+ ·18
4·20	·18	3·69	·35	3·15	·53	2·64	1·40	2·10	1·06	1·76	1·40	1·76
·70	6·32	1·06	·60	1·40	4·92	1·76	3·50	2·10	3·69	2·64	3·15	2·64
− 3·50	+ 6·14	− 2·63	+ 5·25	− 1·75	+ 4·39	− ·88	+ 2·10	− 0·0	+ 2·63	+ ·88	+ 1·75	+ ·88

j.	Bars.	BOTTOM BAYS.									
		a′.	*b′.*	*c′.*	*d′.*	*e′.*	*f′.*	*g′.*	*h′.*	*i′.*	*j′.*
†											
+ 5·60	3	− ‡6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82	− 6·82
+ 4·95	5	− ‡6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19	− 6·19
+ 8·68	7		− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17	− 11·17
+ 7·42	9			− 9·90	− 9·90	− 9·90	− 9·90	− 9·90	− 9·90	− 9·90	− 9·90
+ 6·21	11				− 8·68	− 8·68	− 8·68	− 8·68	− 8·68	− 8·68	− 8·68
− 4·95	13					− 7·42	− 7·42	− 7·42	− 7·42	− 7·42	− 7·42
− 3·72	15						− 6·21	− 6·21	− 6·21	− 6·21	− 6·21
− 2·47	17							− 2·97	− 2·97	− 2·97	− 2·97
− 1·24	19								− 3·72	− 3·72	− 3·72
− 0·00	21									− 2·47	− 2·47
− 0·0	22										− 1·24
− 45·04	Totals,	− 13·01	− 24·18	− 34·08	− 42·76	− 50·18	− 56·39	− 59·36	− 63·08	− 65·55	− 66·79

* † ‡ See Notes to Table 8.

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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 care-

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fully fitted joints, clamped with iron, and cemented with as little mortar as possible.

All the wood-work to be of good sál, sein, or other timber of equal 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. P.

NYNEE TAL,
The 12th April, 1861.

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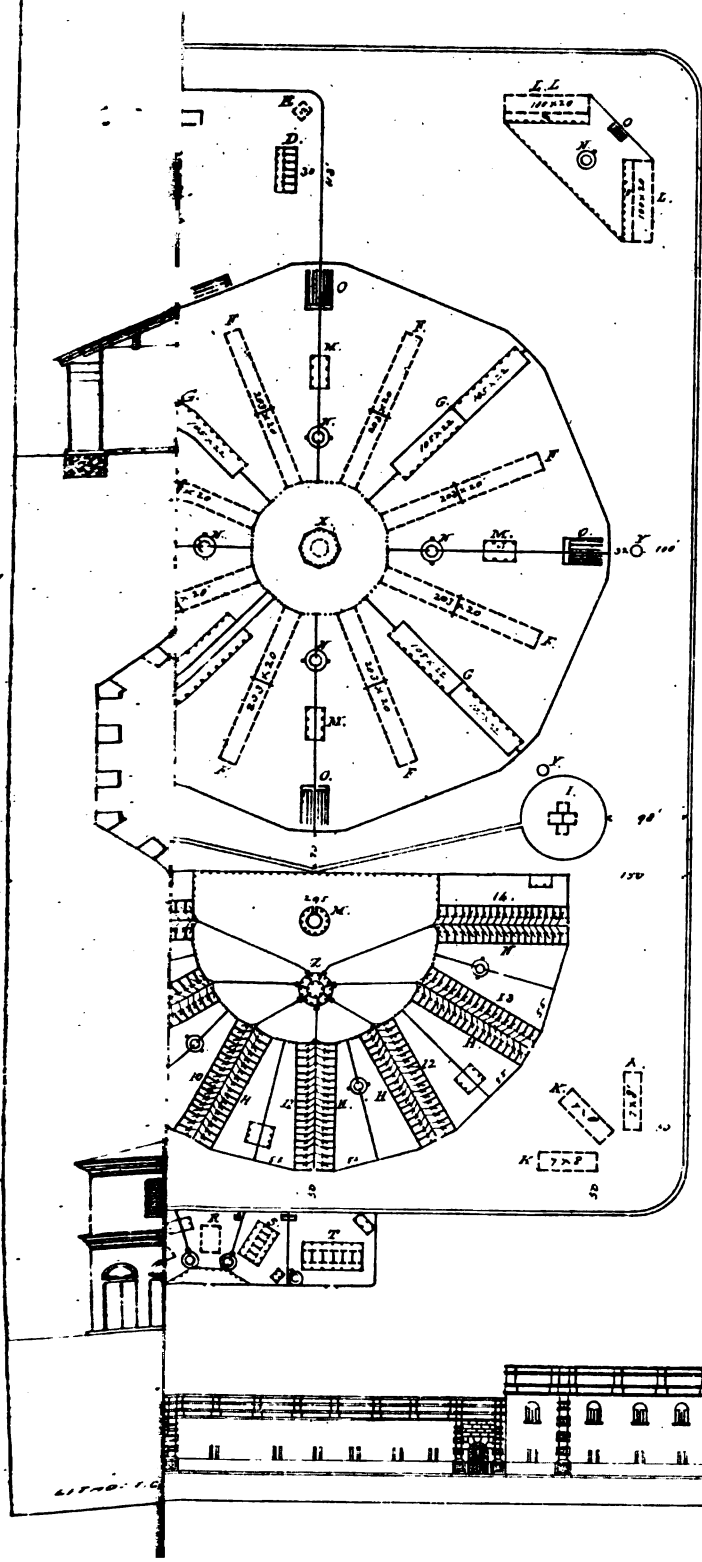
AD.



REFERENCES.

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

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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.

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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

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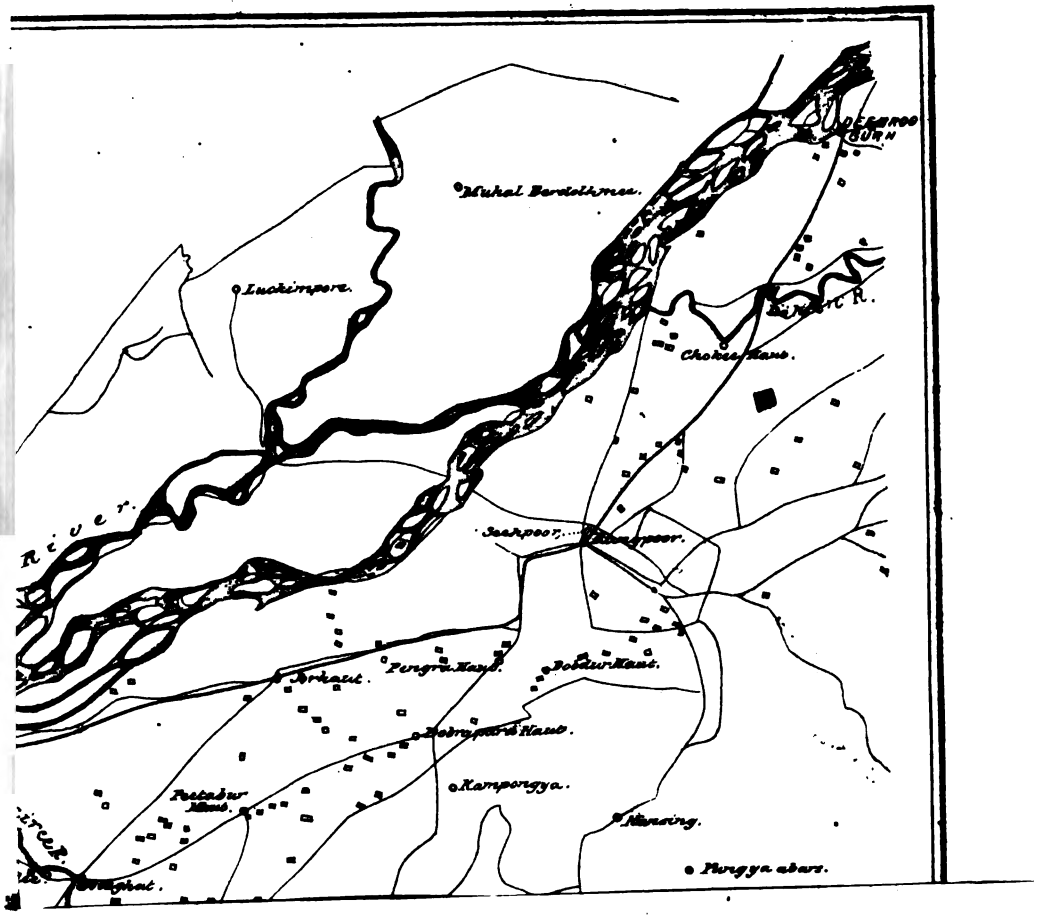
PLATE X.



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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.

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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.

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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 Meekir 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 "Dhodnr 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.

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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.

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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 ex-

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amination 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.,

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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 water-proof 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

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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.

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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.—

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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 Bagaree*, 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 here be observed that with this section Central Assam is supposed to

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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

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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.

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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

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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

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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 143,488 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. 8,88,849.

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

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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.

D. Briggs.

Gowhatty,
5th May, 1863.

[The above project has been sanctioned, and the work is now in progress. Major Brigg's Report on the other Great Road shown in the Map, from Gowhatty to Sylhet, and cutting the Trunk Road at right angles, will be published in the next Number.—Ed.]

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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.

* M. Lallemade, Ingenieur Ordinaire des Ponts et Chaussées.

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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.

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Imperial Road N° 30.

Detail of the Section between market place of St Quentin and 2nd junction with Imperial Road N° 44.

Fig. 2.

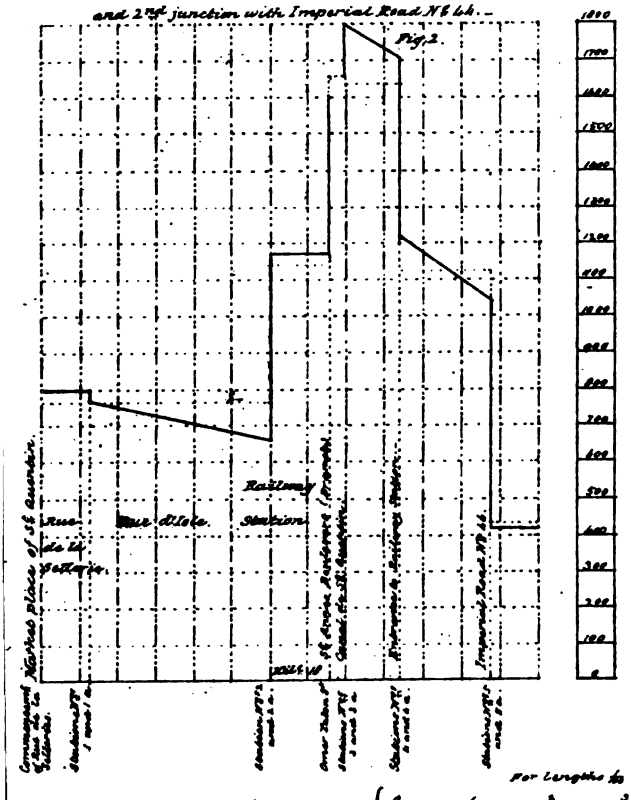

Table comparing results obtained by the Compteur Ambulant with those obtained by observations at fixed stations.

Position of Stations.	Length of each Section.	Mean traffic in each section found by		Difference per Cent.	
		The Compteur Ambulant.	Observations at fixed stations.	More.	Less.
R. 17.30	K. 0,72	799	755	- -	5.5
18.02	0.40	712	757	6.3	- -
18.42	0.15	1169	1126	- -	3.6
1805	0.05	1596	1660	3.3	- -
18.10	0.15	1764	1632	- -	6.6
18.20	0.24	11.38	11.24	- -	1.2
18.48					
General mean.		1025	1020	- -	0,5%

For Lengths in Kilometers.

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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

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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′.

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

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

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′.

$$C_1 = 24{\cdot}7. \quad C_2 = 353 \text{ horses.}$$

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 kilogram; 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

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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

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DAILY CO-EFFICIENTS.

Day of the week.	Ratio of the traffic of each day to mean traffic.	Co-efficients by which to multiply the traffic on each day to obtain mean traffic.
Sunday,...	0·56	1·79
Monday, ...	0·91	1·09
Tuesday, ...	1·06	0·95
Wednesday, ...	1·10	0·90
Thursday, ...	0·95	1·06
Friday, ...	0·99	1·01
Saturday, ...	1·43	0·70
Total,... ...	7·00	7·00

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.

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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.			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.	Total.		
1856.																
1857.																
1858.																

* Or other metalling.

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No. XCIX.

VERTICAL CANAL FALLS,

WITH AND WITHOUT GRATINGS.

[Some Notes on Canal Falls and Rapids having been published in the first volume of this work (p. 37), the more detailed information now given may be acceptable.]

Remarks by Lieutenant J. H. Dyas, *of Engineers, Director of Canals in Punjab, on the Progress Report of the Baree Doab Canal, for the month of November* 1854.

"On the 25th November, two experimental works, Fall No. 17 and Rapid No. 18, were opened, and a considerable body of water, which had been held up since the rains in the excavated canal channel above the Fall, was passed over both works by Lieutenant Duncan Home, of Engineers, in my presence. This having been successfully accomplished, on Monday the 27th the whole supply of the Huslee canal was turned into the new channel above the Fall, passed over both works, and then turned again into its proper course by means of a bund left across the new canal and a second connecting channel below the Rapid. The Huslee had been stopped for a week to enable Lieutenant Home to prepare these channels and bunds, the water not being in great request for irrigation at the time. The supply of the Huslee has been running over the new works ever since.

2. "The object of turning the Huslee supply over the Fall and Rapid* was to try the effect, and to gain some idea of the actual motion, of the

* The Rapid was designed by Lieutenant Crofton, of Engineers. It, like the Fall, has 9 openings of 10·66 feet each, with a drop of 8 feet.

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water over those works; by which means it was hoped sundry improvements might be suggested, and could then be carried out in constructing the remaining works of a similar nature.

3. "Having previously drawn on one of the side walls of the central chamber of the Fall, horizontal and vertical lines, a tenth of a foot apart, and having fixed water-gauges at various points above and below the Fall, a series of tolerably accurate observations was made on the curve of the surface of the falling water, with heads of water above the Fall, ranging from 0·5 to 3·6 feet. In order to obtain so great a head as this, the entire Fall was planked up until the accumulating water rose to 4·1 feet above the crest, when a single bay (10·66 feet wide) was opened as quickly as possible. It took some time to get out the planks, and this had to be done by Lieutenant Home and myself, in the absence of more practised hands, so that the water had fallen from 4·1 to 3·6 feet before the bay was entirely opened, and 3·6 feet is thus the greatest head of water for which observations were made. With a full supply in the canal, the head of water above the Fall will probably be about 4·5 feet. This head gives a discharge over the entire Fall of 3,074 cubic feet per second. A depth of water of 4·5 feet in the canal channel above the Fall (bottom width, 120 feet, and slope of bed, 1 in 1,250), gives a discharge of 3,050 cubic feet per second, which is a sufficiently close agreement. Both calculations being worked out by Dubuat's formulæ.

4. "The result of the trial appeared to me to be satisfactory. The velocity of the water over the Fall was completely destroyed by the resistance of the water in the cistern below. This effect was not of course produced on the Rapid; but the sloping tail walls appeared to act well in protecting the banks, and in directing the force of the current towards the centre of the stream below the work. The masonry (chiefly boulder) of both works is creditable to the builders, Lieutenant Home, the Executive Engineer, Mr. Crommelin, the Assistant Engineer, and Assistant Overseer DeBacker. It was severely tried, particularly in the case of the Fall, considering the green state of the work, and the pressure to which it was subjected.

5. "To try the effect of the falling water on the bottom of the cistern, I took a bottle, and having partially filled it with water, so that it had no inclination either to sink or to float, I tied a long cord to its neck; and having corked it, let it float freely over the Fall. The falling water of course caught it and pulled it under, but by measuring the length of cord

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run out, I found that the bottle could never have been nearer to the bottom of the cistern than 1·5 foot. I obtained a nearly similar result with a bottle filled with water, and consequently heavier than an equal bulk of that fluid. I endeavoured, unsuccessfully, to break a bottle against the flooring of the Fall anywhere. I could not even make the bottle touch the bottom. From this I argue that the bottom of the cistern sustains no direct shock, but there must be a strong current along it. Several bricks, which had been thrown into the cistern were pitched into the air a little above the surface of the boiling wave, which always rises in advance of the falling water. This wave rose to within 2 feet of the level of the crest of the Fall, but it did not seem to affect the velocity of the water beyond it. It did not assume the form of a wave in a state of progression, but as if the water was boiling up from below and breaking or bursting equally on all sides. (Fig. 1). However, owing to the small quantity of water with which we had to deal, the level of the water below the Fall was between 2 and 3 feet lower than it will be with a full supply in the canal, and consequently the height of the Fall was so much greater. In practice, therefore, the boiling wave will not be so formidable.

6. "I was pleased to find that the outer surface of the falling water struck that of the water below, as I had desired, something short of the centre of the cistern. The width of the cistern (measured in the direction of the stream) is 17 feet, and 8 feet is the distance (from the crest of the Fall) at which the falling water struck below. With a full supply in the canal the distance will be about 7 feet.

7. "On the whole, I am satisfied with the new works; they would be every thing I could wish if I could only check the great velocity of the water below the Rapid, and do away with the boiling wave below the Fall. I fear the former is an impossibility, and the only resource is to give additional protection to the banks and bed for some distance below. I have, consequently, directed that double tail walls shall be given to the remaining Rapids.* The space between the two tail walls being paved with boulders, will make a capital cattle *ghât*. I think of checking the wave below the Fall by fixing a sloping grating of wood or of iron work immediately on the crest, so as to divide the sheet of falling water up into several portions, and compel it to fall more perpendicularly on the water

* Given to one Rapid, when further experience showing that the extra tail walls might be dispensed with in that strong shingle soil, the order was cancelled.

Fig 1.

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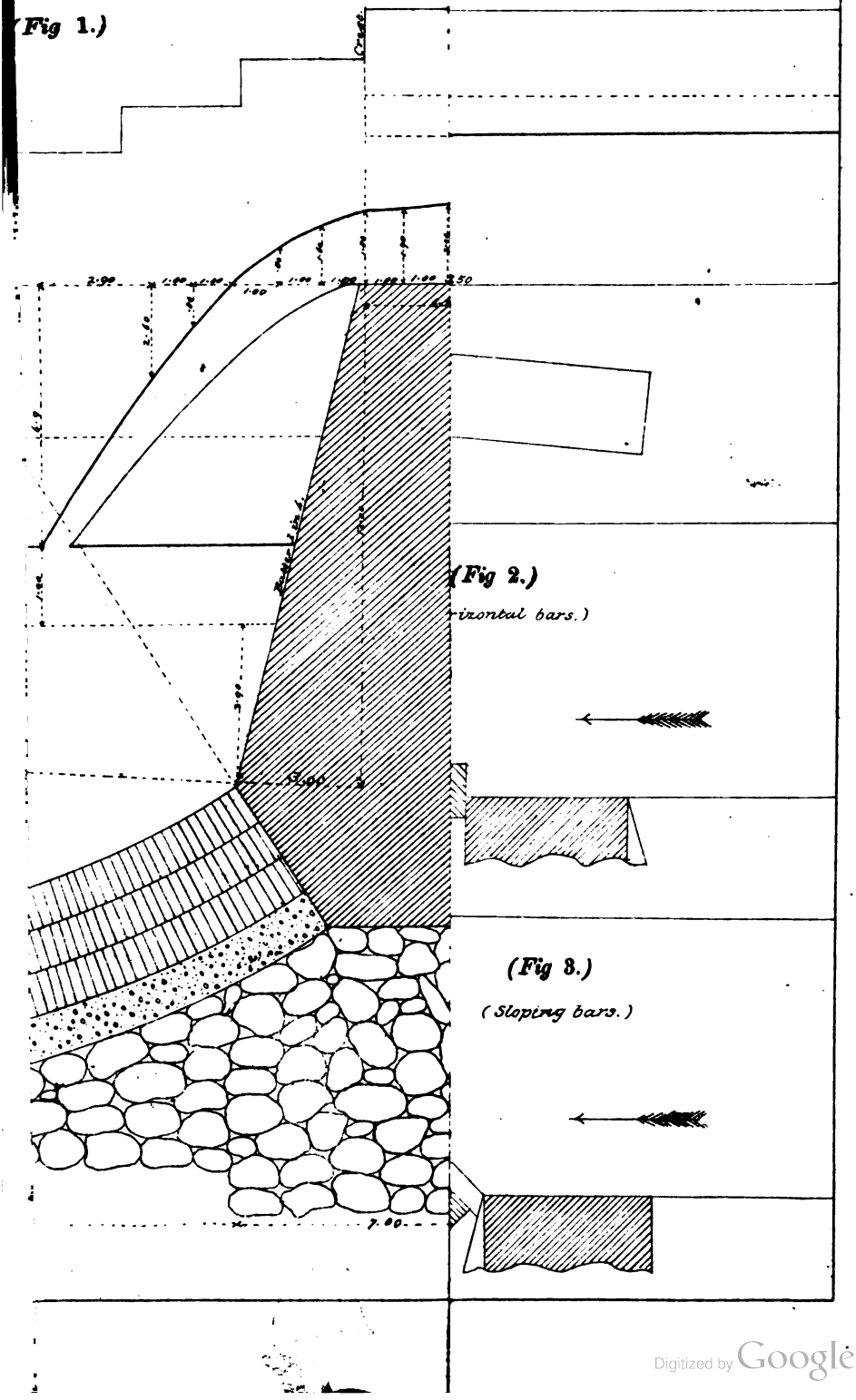

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below, and to take down with it in its fall a large quantity of air which will help to reduce the action on the floor of the cistern. (Figs. 2 and 3).* Other advantages also accompany this arrangement, viz., the prevention of accidents to boats carried down too near the Fall, and of damage to the Fall itself from timber, &c., carried over it. Everything of this nature will be stopped by the grating, and can be taken out there. In the case of lock-channels also, there will be no objection to placing the head of the lock-channel almost close up to the Fall; for the grating will hold up the surface of the water immediately on the crest, so that the proximity of the Fall will not increase the velocity of the water in the channel above it. Possibly, with the grating, a greater length of crest may have to be given to the Fall. I am about to institute a series of experiments on this arrangement, and I will communicate the results. A comparison of cost of the two works is being prepared."

[The following memorandum gives the details of the form of grating adopted after the experiments mentioned at the end of para: 7, of the above remarks. It constitutes Appendix E. to Captain Crofton's Report of 1864, on the Ganges Canal.]

Vertical Fall with Grating.

Memorandum by Captain J. H. Dyas, R.E., *dated* 30*th July*, 1864.

"The grating consists of a number of wooden bars resting on an iron shoe built into the crest of the Fall, and on one or more cross beams, according to the length of the bars. These bars are laid at a slope of 1 in 3, and are of such length that the full supply level of the water in the canal tops their upper ends by half a foot. The scantling of the bars as well as that of the beams should of course be proportioned to the weight they have to bear,

* The form shown in Fig. 2, has the advantage of changing the direction of the falling water to the vertical; but the form shown in Fig. 3 was preferred, and has been adopted, on account of the facility it gives for raking off rubbish. In practice the slope has been made 1 in 3. Fall No. 17, has been run without alteration (as shown in Fig. 1) to this day. The result is that the *counterscarp*, or low retaining wall between the foot of the reverse slope and the invert, has been considerably damaged and worn into a rough slope by the action of the strong current passing over it, and probably by the shocks it has received from logs of timber accidentally passing over the Fall. After the first dive, a log generally comes back again and goes in at the *escarp* or crest wall, like a battering ram, until some one sees it and pulls it out—no easy matter. The wall bears very evident marks of several such encounters.

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plus the extra accidental strains to which they are liable, from floating timber for instance, which may possibly pass between the piers and so come in contact with the grating. In consideration of strains and shocks of this nature the supporting beams are set with their line of depth at right angles to the bars instead of vertically.

2. "The dimensions of the bars used on Falls of the Baree Doab Canal, where the depth of water is 6·6 feet, are as follows:—

Deodar wood.

Lower end of bars, 0′·50 broad × 0′·75 deep

Upper end of bars, 0′·25 broad × 0′·75 deep

and they are supported on two Deodar beams, each measuring 1 foot in breadth × 1·5 foot in depth; the first beam being placed at a distance of 7·5 feet (horizontal measurement) from the crest of the Fall, and the second 7·5 feet beyond the first beam. The bars of the grating on these Falls were originally placed touching each other (side by side) at their lower ends, as there was not then a full supply of water in the canal. There were thus 20 bars in each 10-foot bay. Since then the number of bars has been successively reduced to 19 and to 18, the present number. The reduction of the number of bars and the equal spacing of the remaining bars is done with ease, as they can be pushed sideways in the iron shoe and along the beams, to which latter they are held with spike-nails. Once the correct spacing is arrived at, cleats and blocks (as shown in the drawing) are preferable to spike-nails.

3. "The end elevation of the bars, scale $\frac{1}{8}$th full size, shows the way in which the bars are undercut from the point where they leave the shoe, *i. e.*, from the crest of the Fall. This undercutting has the effect of making each space as it were "an orifice in a thin plate," and it facilitates the escape of small matters which may be brought down with the current. Large rubbish which accumulates on the grating is daily raked off and piled on one side of the Fall. This is done by the establishment kept up for the neighbouring lock. There is considerable advantage in thus clearing the canal of rubbish which would otherwise stick in rajbuha heads, on piers of bridges, &c., or eventually ground on the bed of the canal and become nuclei of large lumps and silt banks.

4. "As one main object of the grating is to prevent the stream above the Fall to which it is fixed from knowing that there is such a thing as a Fall anywhere below it, the principle to go on in spacing the bars is to

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arrange them so that the velocity of no one thread of the stream shall be either accelerated or retarded by the proximity of the Fall. This effected, it is evident that the surface of the water must remain at its normal slope, parallel to the bed of the canal, until it arrives at the grating. The half foot by which the water tops the bars of the grating, as above described, causes a sudden drop there, but the acceleration to the current resulting from so small a Fall as this is not practically felt to any distance back from the Fall.

5. "To take an example, let us assume that V (mean velocity) = 0·81 v (surface velocity), and U (bottom velocity) = 0·62 v (surface velocity) in every vertical line of the current flowing naturally. Then, if we make V = 2·5 feet per second, we shall have the following velocities at the given depths below surface in a stream 6 feet deep.

Depths below surface.	Velocities, (feet per second.)	Remarks.
Surface, ... 0	3·0864	Common difference 0·1955 nearly.
1′	2·8909	
2′	2·6955	
Centre, ... 3′	2·5000	
4′	2·3046	
5′	2·1091	
Bottom, ... 6′	1·9136	

6. "What is required, then, is to shape the sides of a given number of bars placed in a given width of bay so that the above velocities may be maintained till the water touches the grating, when in consequence of the clear fall the velocity becomes considerably accelerated. This accelerated velocity multiplied by the reduced area (of space between the bars) should give the same discharge, with the canal running full, as the product of the original normal velocity and the original undiminished space, the width of which is of course the distance between the centres of two contiguous bars.

7. "Thus, taking the lowest film (along the bed of the canal) whose normal velocity is 1·9136 foot per second, and supposing 20 to be the number of bars in each 10-foot bay, then the undiminished space for each portion of the stream will be half a foot, which multiplied by the above velocity gives a product of 0·9568. Again, taking the same lowest film as it passes

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through the grating, with a clear fall, and under a head of pressure of 6 feet, we find its velocity to be 19·654 feet per second. Now, if we call the required width of space between the bars at this point x_b, and assume the co-efficient of contraction to be 0·6, we shall have $x_b = \frac{0·9568}{19·654 \times 0·6} =$ 0·08 foot.

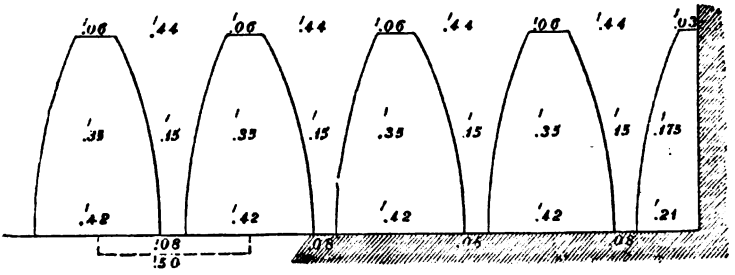
8. "Similarly, taking the film on the level of the tops of the bars, or 0·5 foot below the surface of the water, the normal velocity of which is 2·9887, the undiminished space being as before 0·5 foot, we get a product of 1·4944; and as the velocity of the film falling through the bars is 5·673 feet per second, we get

$$x_t = \frac{1·4944}{5·673 \times 0·6} = 0·44 \text{ foot.}$$

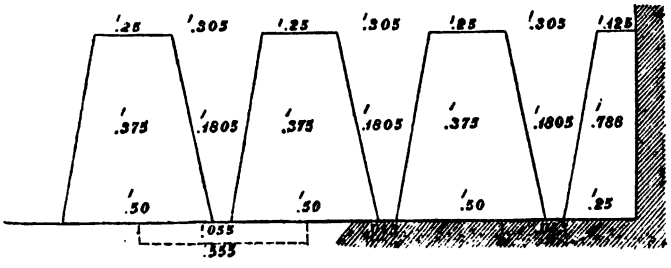
9. "And lastly, taking the centre film, the normal velocity of which is 2·5 feet per second, we have a product of 1·25, and as the velocity of the same film passing through the grating is 13·89 feet per second, we get

$$x_c = \frac{1·25}{13·89 \times 0·6} = 0·15 \text{ foot.}$$

10. "Hence it is seen that the sides of the bars should be cut to a curve convex towards the open space, but in practice this nicety is scarcely requisite.



The effect of cutting the bars straight is of course to increase the discharge through the centre of the grating, and to diminish it at the surface.



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But this is not found objectionable in practice, for, as mentioned in para. 4, the surface velocity has already been somewhat accelerated by the half-foot drop at the top of the grating, and, in consequence of the tendency of the lower part of the grating to clog with matter brought down by the current, there is no risk of undue acceleration to the bottom velocity.

11. "Niceties of detail have not been gone into in the foregoing calculations. For instance, the natural diminution of the velocity from the centre towards the side of the earthen channel has not been taken into account, nor have the obstructions caused by the piers, the slope of the grating, and the accelerating effect (on the velocity through the grating), of the velocity of approach. The object of this paper is merely to indicate the general principle of the arrangement. Those who may have to fix gratings to Falls would of course work out all needful details for themselves, according to the peculiar circumstances of each case; and should practice afterwards show that the theoretical spacing requires correction, the requisite re-adjustment of the bars, is, as explained in para. 2, a very simple matter.

12. "The above remarks have been limited to a consideration of the effect caused by the grating on the channel above the Fall. Its effect on the channel below the Fall is equally important, but this may be gone into separately. For the present it may suffice to remark that the formula in use on the Baree Doab Canal for the depth below the lower bed of the channel is

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

in which empirical equation,

x is the required depth of cistern,

h, the height of Fall, or the difference of level between the surface of the water above the Fall and the surface of the water below it,

and d, the full supply depth of water in the channel.

All the cisterns with depths thus obtained have answered admirably, having never required the slightest repair since they were built.

13. "Another point may be mentioned as worthy of particular attention. The diminution of the waterway immediately under the grating and below the Fall, by the numerous piers of these Falls, as built on the Baree Doab Canal, holds up the water, and causes it to rush out from the bays with considerable velocity. It might be found advantageous to turn arches through these piers, so as to give the water free side-play, or perhaps even to support the gratings and pathway on iron piles instead of on

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brickwork piers. In this case the road bridge, if founded on piers of brickwork, should be moved lower down, to the point where the widening of the protected portion of the channel is greatest. The cisterns also, instead of ending abruptly with a vertical wall, might have their bottoms connected with the bridge flooring by a long counterslope so as to give the fallen water more room and time to get into the true normal velocity of the current in the open channel."

Since the above was written, I have had neither time nor opportunity for making experiments; but Government having lately sanctioned the appointment of an Engineer for the purpose of making experiments, some addition to our stock of knowledge may shortly be expected. Meanwhile the following hints may help inquiry as to the action of water below a Fall.

In July 1863, in the course of some self-acting rain-gauge experiments, having let fall a very slender stream of water into a reservoir, I observed that single bubbles of air, formed by the impact of the falling water on the surface of the water in the reservoir, could be kept for some little time playing at a considerable depth below the surface,* by entering the nozzle of the pipe from which the slender stream was issuing, a very little way below the same surface.

Having long been in search of an easy method of experimenting on falling water, it immediately struck me that here at last was something capable of being turned to account. For the experiments of Sir Isaac Newton on the velocity of descent of bodies in water, having been made with a different object, the bodies (loaded spheres of wax) were let fall from the surface of the water in the reservoir, without any acquired velocity. Experiments even with bodies of the specific gravity of water let fall from given heights above the surface of the water would not suit our purpose as well as those made with the tube; for the addition of a tube or casing to a portion of a large column of falling water would not appear theortically to modify the action of the water below the tube to any great extent; though practically I was unable to dispense with it, because the bubble would not play without the tube. However, not feeling competent to decide the point, or to construct a satisfactory theory, and, after a few experiments made with such rude apparatus as could be improvised, find-

* In this experiment, if the jet be not vertical, the bubble soon breaks through the surrounding inducted current, and gains the surface.

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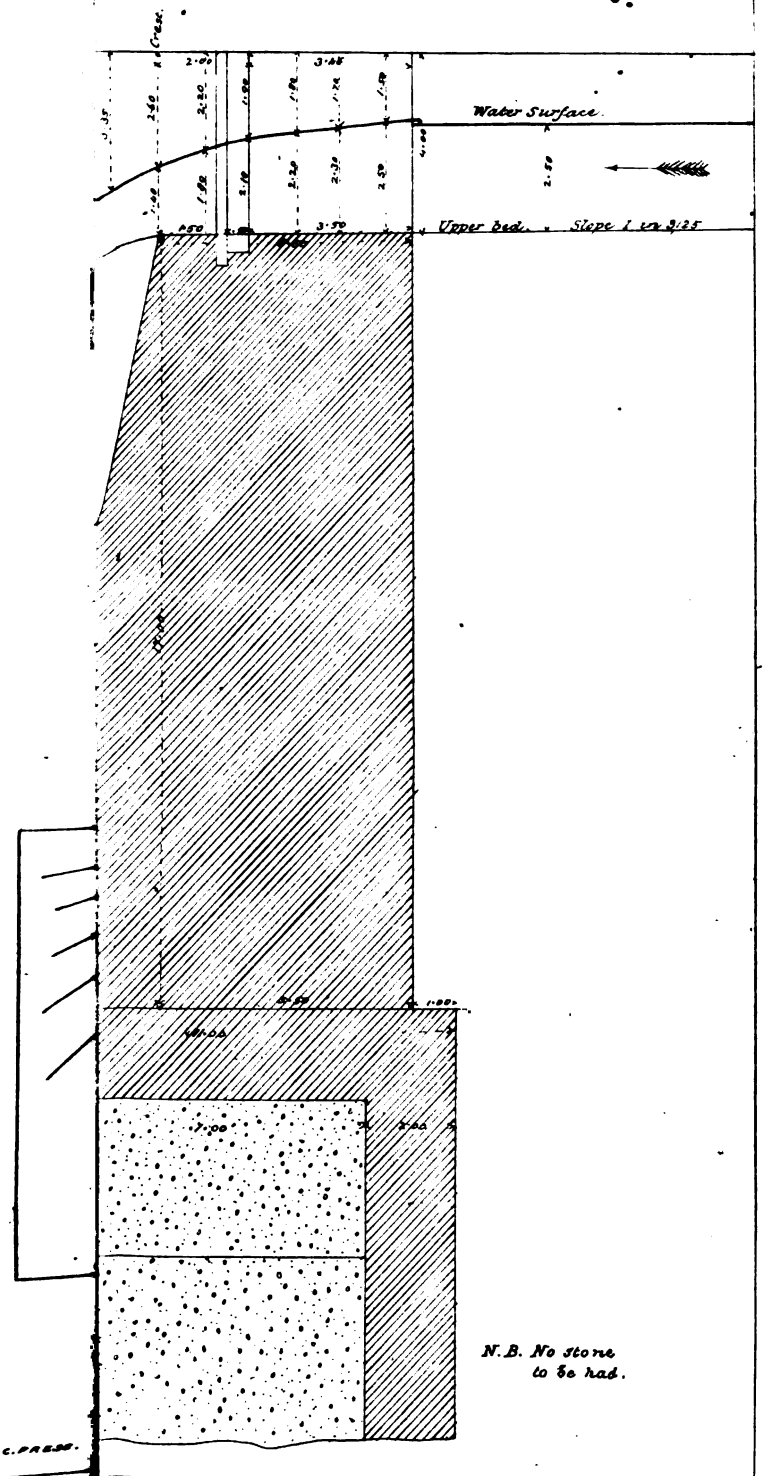
(Fig 9.)



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ing that the distance (Fig. 8) BC of the bubble C below the surface of the water varied tolerably closely as the square root of the height AB of the column of water above the surface, I laid the matter before the first mathematician of my acquaintance in India, who very kindly sent me the following :—

"You have here touched upon a branch of inquiry in which theory can do next to nothing, owing to the fact that the differential equations involved in the theory of the motion of fluids can be solved only in very restricted cases. Experimental results must be looked to chiefly and almost entirely in these problems. No doubt a thorough knowledge of theory in the mind of the experimenter may often help him very materially in choosing and conducting his experiments; but when a problem is given like yours, first to a mathematician, he can do nothing but refer to experimental results.

"The following, however, is a rough approximation to a theoretical formula; which, however, I should not rely upon unless it is confirmed by experiment. (*See* Fig. 8.)

AB $= h$, the height of your column of water,

BC $= d$, the depth of the bubble.

The pressure at B will vary as h; but as this pressure is communicated through the fluid below B, it will spread in all directions in its effect. Say, therefore, that its effect at C varies inversely as d^2, or that the downward effect of the column AB upon the bubble varies as $\frac{h}{d^2}$. It will also vary as the area of a horizontal section of the bubble.

Let radius $= r$; then downward pressure on the bubble arising from the column AB varies as $\frac{h}{d^2} r^2$.

"The upward tendency of the bubble equals the difference of weight of a volume of water, and of a volume of air equal in size to the bubble. The density of air (even when somewhat condensed under water) is a very small fraction of the density of water. We may, therefore, neglect the weight of the bubble of air. The weight of an equal volume of water varies as r^3. When the bubble is just balanced, the upward and downward forces are equal,

$$\therefore \quad \frac{h}{d^2} r^2 \text{ varies as } r^3,$$

$$\text{or } h \text{ varies as } d^2 r.$$

"The density of the air in the bubble varies as the pressure on its sur-

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face, and this varies as the pressure of the atmosphere (= 32 feet of water) + pressure of depth (d) of water. Hence, density of air in the bubble varies as $32 + d$ (h and d being expressed in feet),

$$\therefore \quad r^3 \text{ varies as volume of bubble,}$$

$$\text{varies inversely as density of air in bubble,}$$

$$\text{varies as } \frac{1}{32 + d}$$

$$\text{varies as } 1 - \frac{d}{32} \text{ (if } d \text{ is small compared with 32 feet),}$$

$$\text{or } r \text{ varies as } 1 - \frac{d}{96},$$

$$\text{hence } h \text{ varies as } d^3 - \frac{d^3}{96}.$$

"This is rather rough reasoning, but I do not think that anything more trustworthy can be got from *theory* on this crabbed subject of the motion of fluids."

This memorandum may be appropriately concluded with a section (Fig. 9) of the Neaz-Beg 17-foot vertical Fall, on the Baree Doab Canal, taken 17th January, 1862, before it was fitted with a grating, which was postponed until rendered necessary by the severe action of the falling water on the floorings of the cisterns. Strange to say, notwithstanding Dubuat's accurately drawn figure, one seldom sees the true form of the falling column given, either in drawings of works, or even in figures in mathematical books. Indeed, the general impression appears to be that the column thickens as it falls! and in many designs the cisterns or basins are made short enough for the water to leap clean over them! In this section the measurements were taken to the outer surface of the falling column, and the thicknesses calculated from the velocities at different points. The effect of the air in dissipating such large columns of water can scarcely be appreciable in the comparatively small spaces here dealt with. The actual thickness of the column at any point might easily be measured by inserting a graduated tube, open at both ends, into the column. The observer, looking into the tube, could see when its extremity was just touching the interior surface of the column.

J. H. D.

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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

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"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 after-

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wards 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.

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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.

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FORMS OF LEVELLING FIELD BOOKS.

No. 1. ROORKEE PATTERN.

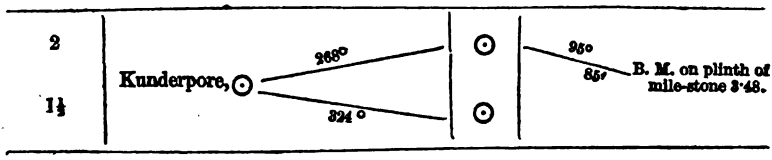
Stations.	Back.	Forward.	Distance.	Bearing.	Rise.	Fall.	Reduced Level.	REMARKS.
1—2	4·56	5·34	600	187°		0·78	451·42 450·64	R. L. of Station 1. (G. T. S.)
2—a	6·18	8·48	85	95°	2·70		453·34	a is a B. M. on plinth of mile-stone.
2—3		5·54	600	187°	0·64		451·28	

Reduced levels always refer to forward station.

No. 2. CANAL PATTERN.

No. of back station.	BACK. Read.	BACK. Bear.	Dist., fr. Inst., to each station.	FORE. Bear.	FORE. Read.	Difference. Rise.	Difference. Fall.	Reduced Level, of back station.
1	4·56	7°	300	187°	5·34		0·75	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.

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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,

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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.

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"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

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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.

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No. CI.

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

(3RD ARTICLE.)

Compiled from a Report by MAJOR-GENERAL SIR ANDREW WAUGH, *Surveyor General, for the years* 1850-51-52. *by* H. DUHAN, ESQ., *Personal Assistant to Surveyor General.*

DURING the years 1850-51 and 52, the operations carried on may be classed as follows:—

G. T. SURVEY.	TOPOGRAPHICAL SURVEYS.
Great Longitudinal Series, finished.	N. W. Himalaya Topographical, nearly finished.
Great Indus Series, commenced.	Rawulpindee and Jhelum ditto, in progress.
N. W. Himalaya ditto, finished.	Ganjam Topographical ditto, ditto.
Rahoon Meridional ditto, commenced.	Peshawur Frontier ditto, finished.
N. E. Himalaya Longitudinal ditto, finished.	
Hurilone Meridional ditto, ditto.	
Parseratt ditto, ditto, ditto.	
Assam Longitudinal ditto, commenced.	
Coast Series ditto, in progress.	
Bombay Trigonometrical Survey, ditto.	

The Great Longitudinal Series, extending from Sironj Base to Karachi, was the most important and interesting of the works in progress, as the accurate geography of the whole of western India, and connection of Sind depended on it. Its commencement under Capt. Renny Tailyour was noted above.

In Nov. 1850, operations were commenced by Captain Strange at

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Gooroo Siker hill station, the highest point above mount Aboo, and the observing party pursued its course along the northern flank of the series returning by the southern. They then advanced westward and finished the observations at the stations, forming a double hexagon west of the Arabulli range; on concluding which, field work for the season was discontinued.

Captain Strange describes the Arabulli mountains as an extensive tract, having a general north and south direction, composed of ridges and peaks, which though attaining no elevation greater than perhaps 5,500 feet above the sea, yet exhibit in the details that compose them all the boldest features of the most stupendous mountain scenery. In many parts of this tract, there are no roads whatever. Nothing meets the eye but vast blocks of granite towering aloft, and jungles almost impenetrable obstruct every step. The habitations of men are seldom met with, and man himself as here found, roams a lawless savage.

This brief description is necessary to explain the peculiar nature of the difficulties to be surmounted; especially in the transport of the Great Theodolite over such ground, which was a matter of great anxiety and responsibility. And, in addition to the physical difficulties presented by the Arabulli tract, the impediments were enhanced by the unwillingness of the inhabitants to render assistance.

Captain Strange's practical skill as a mechanic was this season called into requisition, on account of the balance pivot of the sidereal chronometer breaking, apparently from being eaten by rust. After three days' most anxious labor, he was so fortunate as to succeed in his endeavors to repair the damage completely; and the chronometer, on being tested, was found to keep its rate as well as before.

The party broke ground again on the 1st November, 1851, and proceeded to the Desert. This tract being destitute of food, such as the men were accustomed to, and the grain used by the inhabitants being barely sufficient for their own wants, it was indispensible that arrangements should be made for the supply of provisions, the nearest places from which this could be procured at moderate prices being Deesa on the one extremity, and the Sind towns on the other.

It was clear that success depended chiefly on traversing the desert at the best season, which being brief in duration, it was necessary that

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the rate of progress should be accelerated as much as possible, so as to endeavor to reach in that short time the plains of Sind, being a distance amounting to 3° of longitude.

The Desert, commonly known among the natives as the "thur," and geographically termed the Little Desert, is throughout composed of sand hills, whose general forms are long and straight ridges, which seldom unite, but stand at close and regular intervals parallel to each other. The ripple on the sea shore affords a fair illustration in miniature of the formation of the ground. Some of these sand hills are perhaps a mile long, and vary from 50 to 300 feet in height, their sides being deeply channelled by rain, and their general appearance from a distance differing little from that of ordinary low hills. These are evidently permanent, and Captain Strange heard of none which were known to shift. There is more jungle than might be expected in a desert, but it is low and almost leafless. The whole desert in the cold season is clothed with grass, attaining in many parts a height of two feet. It is then much resorted to for pasturage by the owners of large herds, by whom it is deserted on the approach of hot weather. The permanent population is of course scanty, and their villages scattered at intervals of 8 to 12 miles. A herd of cattle, a few camels and a well, constitute the wealth of a village, no cultivation being attempted except during the rains, when an uncertain crop of millet (bajri) is obtained. A fine race of men inhabit this inhospitable region. Athletic in frame, independent, cheerful and civil in demeanor; intelligent and brave; they only require to abstain from their favorite pursuit of cattle lifting, to rank above almost any other tribe in India. The villages in the desert, though invariably distinguished by a name, cannot be considered strictly speaking fixed localities. Their permanence is dependent solely on that of the wells; as long as that affords sufficient water of passable quality, the village remains standing. But the wells of the desert are liable either to cease flowing or to become too brackish even for the use of the inhabitants or their cattle. The spot is then deserted and water found elsewhere, nearer the surface, and of better quality, though still brackish.

Travelling in the desert is exceedingly laborious to men carrying loads. No sooner is one sand hill passed, than another presents itself. Their sides are very steep, and every frequented tract is converted into

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deep loose sand, into which the feet sink to the ankles. No wheel carriage is used; nor are loads ever carried voluntarily by the inhabitants, otherwise than on camels, the only fit conveyance on such soil. Indeed, the men of the desert rarely walk, every man possessing a camel. The air over the desert in the cold months is very transparent, which circumstance greatly favored the observations, and contributed to the great success which attended the enterprise, notwithstanding the difficulties of transport, and the deficiency of wood and water, for which judicious provision was timely made.

The transition from the Desert to the plains of Sind is surprisingly sudden. In the space of a hundred yards the traveller leaves sand and sand hills, and enters a perfectly flat country, with a firm black loamy soil. Inhabitants, customs, language and vegetation, are exchanged with the same startling abruptness. The soil is hard, black and devoid of grass; jungle plentiful and thick; the country populous and cultivated, and intersected in every direction by irrigation canals, dry in the cold season. Such a country is very unfavorable to trigonometrical operations. Road tracing and clearing, check the progress of the approximate work; the necessity of building towers causes further delay and expense, and bad signal lights embarass the observations. This tract fortunately involved only $3\frac{1}{2}$ hexagons, after which hills extended to the termination of the series at Karachi.

The Desert was found perfectly free from mirage at the season it was visited, but the Runn of Cutch on the southern flank of the series was greatly affected by this atmospheric peculiarity, which prevented the ascertainment of a point the Surveyor General was anxious to determine, viz., the height of the Runn with respect to the sea level, a matter of great interest. The Runn, or salt marshes, are supposed, from traditionary accounts, to have been caused by eruptions from the sea, during storms or earthquakes. In this case the tract may either lie at ordinary high water level or form a basin below it. To determine this, a secondary point was established in the Runn, and vertical angles taken to it from Akoria station, on the edge of the tract, but the point could not be connected, and the verticals were so affected by mirage as to be untrustworthy.

Mr. Rossenrode extended the approximate series in advance to Karachi, where he succeeded in selecting suitable ground for a Base of

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verification, connecting it symmetrically, so as to enter into the last hexagon as a side of a principal triangle, thus avoiding supplemental points; agreeably to the instructions laid down for Base Lines.

It was an object from the outset to cross the Desert in one season, and as the favorable time was limited, and the number of Azimuth stations for circumpolar star observations was much larger than usual, it was a matter of anxiety to complete them. The number of azimuth stations being 9, the star observations would have occupied no less than 36 days of uninterrupted fine weather. To shorten this period, observations were taken on two zeros at each elongation, an alternative adopted in previous cases, but which requires considerable practice to achieve successfully.

This series, commenced by Captain Renny Tailyour, was thus continued and completed by Captain Strange in 1852, with the exception of the measurement of the Karachi Base, which was postponed till the following season. The extent of the arc of longitude is 10° 37′, equivalent to 668 miles in length, covering an area of 23,099·07 square miles. The rate of cost was Rs. 6-12-10 per square mile.

N. W. Himalaya Series.—This series was commenced by Brevet Major Du Vernet in 1847-48, and carried in three seasons to the Maharajah of Kashmir's territories. He was succeeded by Mr. George Logan, 1st Assistant.

The Great Theodolite, by Barrow, being too heavy for transport in the mountains, without cutting roads for its passage, one of Simm's new 24-inch Theodolites was used. The observations were carried out without interruption till the end of March 1852, during which period the final angles of twenty-one great triangles, covering an area of 6,665 square miles, were observed, and the positions of sixty-nine secondary points determined.

It was an object of first importance to select the site for a Base line of verification at the junction of this series with the Indus triangulation. With this object in view the Surveyor General himself proceeded to co-operate in this duty.

The valley of Peshawur was the site formerly indicated for the Base line in the original project of these operations, on account of its advanced position, near the extremity of the Empire. The Surveyor General was, however, induced to alter this plan upon considerations

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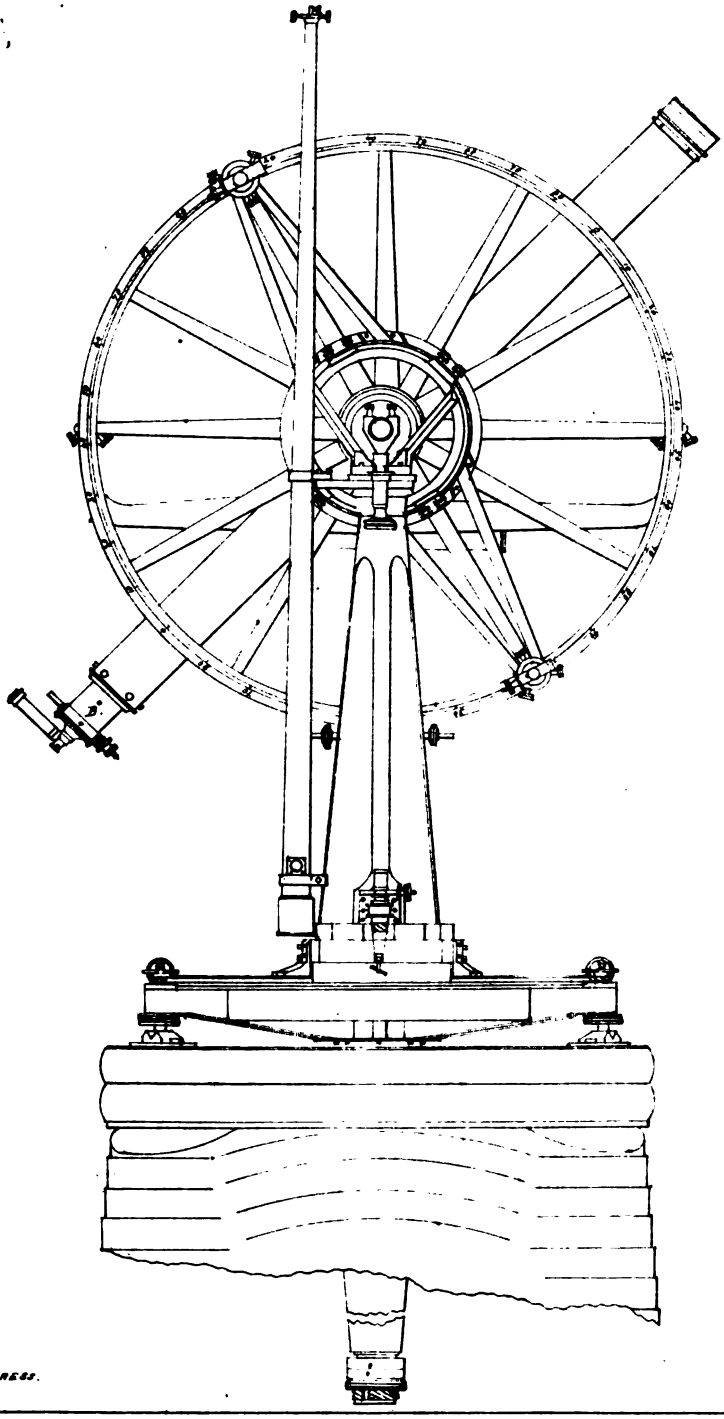
THE ASTRONOMICAL CIRCLE.

Constructed by Messrs. Troughton and Simms, for the G. T Survey, India



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depending on the political state of the country. The whole valley was liable more or less to incursions from the adjacent lawless tribes of Afridis and Khattaks, and as the measurements of a Base of eight miles' length occupies upwards of two months, and a large party must be assembled in the close vicinity of the disaffected tribes, they would have been attracted by hopes of plunder and the apparatus exposed to much risk. Any injury to the Standard Bar, or any of the important parts of the measuring implements, would have been irremediable. It was also ascertained that none of the stations Trans-Indus, which were necessary for connecting the Base, could be occupied for the length of time necessary for observations of principal triangles. For these reasons of policy, therefore, the Surveyor General determined to take up a line in the valley of Chuch not far from Attock, on the east side of the Indus, where all the conditions requisite for a Base of a superior order could be obtained without risk. Thus the great triangulations of the North-west Himalaya Series and of the Indus Series terminated in Chuch, and the triangulation extending to Peshawur is considered a branch series.

This important branch series fell to the lot of Mr. William James, who was equipped with a 14-inch theodolite, well suited to expeditions of this nature, requiring good work and celerity of movement. These instruments are portable enough to be carried anywhere, and are so accurately graduated by Mr. Simm's self-acting engine, that a few observations give results but little inferior to those derived from instruments fitted with micrometer microscopes.

Mr. James received every assistance from Captain James, the Deputy Commissioner of Peshawur, and from Captain Lumsden, commanding the Guides. At Zakt-i-Bahi, a lofty hill station, which was an indispensable point for the series, there was cause for apprehension, on account of a body of Swat horsemen, about two hundred in number, who had descended one of the valleys and pitched within six miles of the hill. To protect the survey, Captain Lumsden detached a troop of the Guide corps.

The operations effected this season by Mr. Logan's party may be summed up as consisting of twenty-one principal triangles, and 117 secondary ones, covering an area nearly amounting to 10,000 square miles. A connection was established with Lieut. Walker's survey

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of the Trans-Indus frontier, which will be noticed further on, and the positions of thirteen of Lieut. Robinson's stations ascertained on the skirts of his Hazara survey. The series had been successfully carried to Peshawur and advanced down the Indus, as far as Kalabagh.

On the termination of these proceedings, the measurement of the Chuch Base line would have been proceeded with, but owing to Departmental reasons it was postponed till the season 1853-54. To Mr. Logan's party therefore was assigned the Rahoon Meridional Series, which is next to (west of) the Great Arc. In making this arrangement the Surveyor General had in view to supply with all practicable expedition fixed points of geographical reference, which had for some time been urgently wanted for the Revenue Survey of the Cis-Sutlej States and the canal operations in Rhotuk.

It has been previously stated, that from 1850-51 the geodetical part of the North-west Himalaya Series was made over to Mr. Logan. This arrangement left Major Du Vernet free to devote his whole attention to the topographical survey of the mountain districts, which it was an object of primary importance to get out of hand speedily, as no correct maps existed of these parts.

These Mountain Topographical Operations comprise the whole tract included between the plains on the south, and the frontier of Ladak and China on the north, and from the kingdom of Maharaja Goolab Sing on the west to the Ganges on the east, on which side it involved the revision of a portion of General Hodson's survey of Gurhwal and Simla, which was imperfectly delineated, and could not be combined satisfactorily with the hill drawing of the newly acquired tracts. Thus the country to be surveyed is naturally divided into three parts, viz:—

1*st*. The Sub-Himalaya mountains.

2*nd*. The Himalayas proper, or barrier of perpetual snow, with its spurs rising into peaks, forming the most stupendous pinacles on the globe.

3*rd*. The tract beyond this barrier, consisting also of mountains covered with perennial snow, intersected by valleys, constituting the beds of the great Punjab rivers, having their origin in the snowy region.

Each of these tracts is environed with difficulties peculiar to itself,

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both climatic and physical, and there is no part of the entire region which does not present impediments of the most formidable kind to survey operations; owing to the rugged nature of the country, the difficulties of transport, and scarcity of provisions. The Sub-Himalayan tract, though only covered with snow in winter, is during summer subjected to the full force of the monsoon, by which it is deluged to the extent of at least 100 inches. During this season the hills are covered by mists, which impede vision and prevent all progress. On the other hand, the region of perpetual snow can only be penetrated by a few passes, which are open at certain periods, are frequently dangerous to transit, and far more so to linger in for survey purposes. The tracts beyond the snowy barrier, although enjoying a beautiful climate in summer and free from tropical rain, can only be attained by crossing snowy passes, over which it is almost impracticable to triangulate, and which are liable to be shut up by early falls of snow.

Thus it will be seen that the topographical survey of these tracts was an enterprise of no ordinary character, nothing analogous having been attempted before. The plan determined on was strictly of a trigonometrical character, depending on continuous Triangulations, filled up with regular Plane Table surveys. The difference of character in the tracts before-mentioned, indicated the necessity for a corresponding difference in the periods of surveying, and the party was accordingly subdivided into several detachments, to each of which specific duties were allotted.

During 1850-51, the triangulation of 436 miles in length was completed, comprising 528 first and second class triangles, with the determination of the height of about 300 points above the sea, independent of barometrical observations in the valleys. The details also of 13,470 square miles were effected, giving an excellent delineation of the nature of the country.

In a country containing such vast mountain masses, great disturbances must take place in the direction of gravity by reason of the irregular attraction prevailing. On this account nothing can be concluded from the observed azimuths, nor can a very close agreement be expected in the computed azimuths. The peculiar difficulties of the country did not admit of the highest degree of geodetical symmetry being attained, nor in such a rigorous climate could the observers remain long enough

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on elevated stations to multiply observations. The work cannot therefore be fairly judged by ordinary rules; nevertheless, the agreement in latitude and longitude is throughout satisfactory, as also in the linear values and elevations above the sea.

The country, rugged and perilous in the extreme, is almost wholly without means of communication for ordinary travellers, and the difficulties are infinitely enhanced in the case of surveyors, who have to deviate from such tracks as exist, and visit lofty stations on commanding eminencies, many of which have never before been trodden by the foot of man. The rivers are formidable impediments, being foaming torrents. The bridges consist of two trees, laid across and supported on corbels composed of other branches of trees; or hawsers are used, formed by twisting twigs of silver birch, on which the traveller is dragged across, lashed to a running tackle, attached to a collar formed of a pronged stick. Trying as such a mode of transit is to the nerves of persons unaccustomed to such scenes, the anxiety is much enhanced in the case of surveyors, responsible for delicate instruments on which the success of their labors and consequent reputation, depend. In many cases the stations of observation were 18,000 feet above the sea.

The maps of this mountain survey, for the sake of expedition have been brought out in degree sheets, of which there are fourteen.

By the end of the season 1851-52, the whole British mountain provinces, from the Maharaja of Kashmir's boundary on the Ravee as far as the Ganges, were surveyed. There remained a gap or hiatus in the map, occasioned by the want of a regular survey of the Maharaja of Kashmir's territory, a project for the survey of which was sanctioned by the Supreme Government, and will be reported on hereafter.

The North East Longitudinal Series extends from the Base in Dehra Doon to the Sonakoda Base, in the district of Purneah in Northern Bengal. It is a most important chain of triangulation, owing to its great length (704 miles), its situation skirting the northern frontier of the Empire, and finally because it verifies all the meridional series between the meridians of the Great Arc and Calcutta. This work was completed by several parties from time to time, by means of triangulation, connecting the termini of the several subordinate meridional series. The operations were therefore of a piece-meal character, and the final connection was completed by Mr. George Logan, as previously

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described. The only part of this long series of triangulation which had been effected by an inferior instrument, was the mountain portion, executed in 1842-43 by Major Du Vernet, with an 18-inch theodolite, which had been graduated in India by Said Mohsin. The graduation of this instrument was proved to be unsatisfactory, which caused large discrepencies in the results of the triangulation. This portion was therefore revised with a superior instrument by Captain Renny Tailyour in 1850-51, with the result that the comparison of the Budhon Meridional Series with the North East Longitudinal Series, now differs only 0·3 inch per mile, whereas the previous difference was 3·3 inches per mile.

The great improvements effected in the heights of the original series, arising from improved and more rigorous methods of taking the verticals, have already been noticed. The completion of the North-east Longitudinal Series filled up an hiatus in a grand circuit of triangulation, extending from the sea level at Calcutta round by the Himalaya mountains, to the same datum at Bombay. The result of this severe test was anxiously looked for, as it serves to prove the accuracy or otherwise of the trigonometrical values above the sea level in upper India.

With respect to the subject of trigonometrically determined heights, the Surveyor General writes, "It may be premised that when we reflect on the vast extent of the British Empire in India, including an area of survey amounting to 1¼ millions of square miles, of which a very large portion is situated at a great distance from the sea, the Trigonometrical Survey of India labors under peculiar disadvantages as respects the inconvenience of determining heights in that remote portion. The whole of northern Hindostan can be connected with the sea only by means of operations averaging at least 1,000 miles in length, and no verification or test of accuracy can be obtained but by referring again to the actual sea level at the termination of the operations. Hence, I have always felt great anxiety concerning the value of our unchecked heights in upper India."

The Trigonometrical levelling along the Great Arc was brought up from the sea at Cape Comorin, and is unchecked along the whole course of the series, extending no less than 1,540 miles to the Himalaya mountains. It is also to be borne in mind that the southern sections

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of the Great Arc as far as Beder were executed with instruments constructed before accurate levels were invented. At the same time the laws of terrestrial refraction, which even now are obscure, were in those days still less understood, nor were precautions now deemed necessary in observing vertical angles, recognised at that period.

From the Beder Base, the Bombay Longitudinal Series branches westward, and after a course of 314 miles connects with the sea at Bombay. The operations of this series were skilfully conducted by Captain Jacob, whose instruments was furnished with a good level. This series has the advantage of a hilly country and short course. It may, therefore, be expected to be free from any great accumulation of error, and the value of the height above sea level thus brought up from the sea at Bombay to the Beder Base may be reckoned trustworthy. The Great Arc Series from Beder Base to Banog observatory is 864 miles in length, of which nearly 200 miles traverse the valley of the Ganges by means of towers, and are unfavorable for determining heights. The instruments used were however of a superior kind. The North East Longitudinal Series from Banog observatory to Sonakoda Base, is 704 miles in length, of which the greater portion lies in flat lands unfavorable for Trigonometrical levelling; but the instruments and processes used were entirely modern, and every precaution was adopted and refinement attended to, which the nature of the undertaking admits of. The Calcutta Meridional Series from Sonakoda Base to the Barackpore Base, is 250 miles in length, and likewise traverses a flat country, as described above.

Thus the aggregate length triangulated from the sea at Bombay to the sea at Calcutta, round by Upper India is 2,132 miles, and the results of Trigonometrical levelling along this circuitous course give a discrepancy of only 3·6 feet, a degree of precision which is astonishing, considering the vast distance and the nature of the intermediate countries. The whole of these operations are modern, and executed with instruments furnished with delicate levels, the observations having been taken by experienced observers, and the result shows that a refined degree of accuracy is attainable by Trigonometrical levelling, when the precautions requisite against intrusion of error are rigorously attended to.

The Great Longitudinal Series, which has been extended to the sea at

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Karachi, furnished another test which was equally satisfactory. The most rigorous mode, however, was to bring up the level from the sea by regular Spirit Levelling operations, which were carried out as will be shown hereafter. In the meantime the Surveyor General was not unmindful of the other independent test obtainable by barometrical observations. A series of such observations was instituted with this object at the observatories of Banog and Dehra, simultaneously with similar observations at Calcutta. The results indicate values a little in excess of the trigonometrical levelling, which is precisely what may be expected from the following considerations. First, it may be remarked that when a barometer has been compared with a standard near the sea level, and is removed to a distance for the purpose of observing at greater elevations; if the slightest derangement takes place, it will, by lowering the barometric column, indicate an excess of height. Secondly, Trigonometrical levelling originating at the sea proceeds inland; consequently the plumb line must have an inland deflection, on account of the greater attracting mass on that side, and this will tend to raise the apparent horizon on the inland side, and thus diminishes altitudes. Although the amount of such abnormal deflection may be very small; still, in operations extending 1,000 miles, one second of deviation would amount to 25 feet in the height. As we approach the Himalaya range, the attraction becomes considerable, amounting to about 30 inches on the lower hills. For these reasons it is to be expected that the results of all levelling operations in Upper India, depending as they do on the direction of gravity, will accumulate a small error in defect, as regards altitudes above the sea level.

The North-east Longitudinal Series having been completed, the triangulation completed from the Dehra Doon Base as an origin, and carried down to the Sonakoda Base of verification, exhibits a linear discrepancy of 5·92 inches per mile, as shown by the following statement, viz.:—

Length of Sonakoda base line.	By measurement in feet, ...	36,685·81
„	Brought down by triangulation,	36,682·88
	Differences, ...	3·43

This discrepancy is somewhat larger than was anticipated from the power of the instruments used, the experience of the observers and the great pains taken to ensure accuracy. It may be explained, however,

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by the peculiar circumstances of the country traversed by the triangulation. The series is 704 miles long, of which distance more than 500 miles passes over flat lands, situated in or bordering on the damp unhealthy forests called the Terai. The whole of the tract is unfavorable for observation, and from the absence of natural elevations, towers averaging from 20 to 40 feet were constructed for the stations of observation. Although the signals were thus rendered visible, the rays were more or less grazing along the ground. The towers also were subject to settlement, by which the upper marks were liable to deflection. From measurements which were taken, it appeared that in some instances settlements had taken place which deflected the upper mark nearly one foot. On this account a new plan of tower was devised, which in future will prevent the intrusion of error from unequal settlement, in towers for observation.

After completing the geodetical operations on the mountain part of the North-east Longitudinal Series, Captain Renny Tailyour was employed in astronomical operations for determining Himalayan attraction at the observatories at Banog and Dehra. The method of observation adopted was as follows :—

On account of great mass of geodetic computations on hand, it was desirable to adopt a method of determining the absolute Latitudes of Banog and Dehra, with their reciprocal Azimuths, such as would simplify computation, while at the same time the results would be as accurate as the means employed admitted; with this object, the stars were taken from the Nautical Almanac, to save time in deducing apparent places, and likewise because the places of those stars are better determined than any others. The stars to be observed were selected in pairs, so as to give as nearly as practicable equal zenith distances north and south, and thus eliminate as much as possible errors of refraction and of graduation. It was also an object to select pairs of stars differing 7 or 8 degrees from each other in altitude, between the elevation of the pole and zenith, so as to disperse the readings over the limb at nearly equal intervals apart.

The instrument used was a 24-inch theodolite by Simms, having an 18 inch vertical circle, beautifully graduated by his self-dividing engine. The stars were observed on the circum-meridian principle, except in the case of the pair nearest the zenith, which were taken upon alternate

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faces in successive nights, and corrected for collimation error by a mean correction derived from all the other observations. The rates of the sidereal chronometer were obtained from transits of a high and low star.

The results of Captain Tailyour's observations were most satisfactory, and the final values deduced for the attraction in Latitude and disturbance in Azimuth are—

	At Dehra observatory.	At Banog observatory.
Observed Latitude in defect of computed geodetical Latitude brought up from Kalianpore, ...	37″·675	32·96
Observed Azimuth in defect of computed geodetical Azimuth brought up from Kalianpore, ...	17·858	20·156

These results confirm the opinion previously expressed by the Surveyor General, that the hypothesis of a fixed centre of attraction is altogether untenable with respect to so extensive a range of mountains as the Himalayas, of indefinite length and breadth. Even if the position of such a centre could be fixed by a combination of astronomical observations, it would still be necessary to determine the intensity of the force or equivalent mass, which, concentrated in that centre, would produce the same attraction as the mountains do in their existing forms and position. Thus the determination must depend on an independent calculation of the attractions of all the parts of the mountains in detail, and this the progress of the topographical survey may in time render feasible.

By means of an independent calculation of the sum of the attractions exerted by the mountain masses, the amount of the meridional deflection at Kaliana may be ascertained to a considerable degree of accuracy, and its effect may be thus eliminated from the northern terminus of the Great Arc. The Venerable Archdeacon Pratt concurred with the Surveyor General in this opinion, and considered the undertaking highly advisable. The calculation will be a matter of great labor, and the data required are an accurate survey of the mountains, with sufficient determination of heights to enable approximate sections of the principal masses to be drawn. Sufficient data for this purpose are not at present forthcoming. The recent survey of the mountain region extends from the meridian of the Great Arc to the Maharaja of Kashmir's country. The attractions of all the parts of this tract are resolvable into the plane of the meridian. The heights of the prin-

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cipal ranges are determined, but a greater number of vertical ordinates would be required for the purpose of estimating the masses.

By the satisfactory conclusion in 1852 of these two series, the plan of operations originally projected by Colonel Everest has been completed, whereby the triangulation of the whole tract has been finished between the meridians of the Great Arc and of Calcutta, and between the parallel of 23° and the northern frontier of the Empire. The services of the Parsnath party were accordingly transferred to the *Assam Longitudinal Series*, which was designed to commence from the Sonakoda Base, and to proceed eastward to the north-east extremity of the Empire.

The Hurilong and Parisnath Series were completed by Mr. Armstrong and Mr. Nicolson respectively in 1852, and further progress made in the Coast Series in spite of great difficulties caused by sickness and the peculiar physical impediments before adverted to. The Bombay party was employed during this time under Lieut. H. Rivers of Engineers, on the Mount Aboo Meridional Series. The northern portion of the series is in the mountainous district, in which the Saburmuthi, West Bunnas, and other Guzerat rivers rise. Great difficulty was experienced in moving about and carrying on the work. The few inhabitants are in quite a lawless condition, and in fact professional robbers; but in spite of all difficulties the progress made was satisfactory.

Shortly after the Sutlej campaign of 1846, Lieut. Robinson of Engineers, had been deputed in the Political Department to survey in conjunction with the Boundary Commissioner, Major James Abbot, the limiting line of the Maharaja of Kashmir's territories, after which he was employed on a military survey of Hazara. On the completion of these duties he was placed under the orders of the Surveyor General for the purpose of being employed in the survey of the Salt Range, and eventually of the Derajat. The system of survey adopted for delineating the boundary was a minor series of triangles based on the great triangulation and connected with a traverse (Gunter chain and theodolite) survey along such parts of the boundary as admitted of chaining, but the rugged ground cut up with ravines depended on triangulation alone. The general map was completed by the end of 1851.

(To be continued.)

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THE PUBLIC WORKS DEPARTMENT.

In the first Volume of these Papers, a description was attempted of some of the specialities of Indian Engineering, for the benefit chiefly of English readers. I have since been asked to give some further account of the agency by which the system of Indian Public Works is carried out and controlled, and must trespass on the patience of Indian readers while giving a brief sketch of the composition and working of the Public Works Department.

Up to the year 1854, the control of this important Department was vested in the Military Board, which, having in addition, to superintend the business of the Commissariat, the Pay, the Clothing and the Ordnance Departments, was unable to attend properly to the wants of any one in particular. Under Lord Dalhousie's administration, therefore, the Military Board was broken up; the various Departments under its control were put on a separate and responsible footing, and the arrangements now in force (allowing for sundry modifications since introduced) were initiated, the Public Works Department being placed under the direct control of Government exercised through a newly constituted Secretariat.

The Secretary to the Government of India in the Public Works Department is virtually the head of the Department, and the responsible adviser as well as mouth-piece of the Governor General in Council on all questions connected with the Public Works of India. He has an Under Secretary and several Assistant Secretaries to aid him, besides, of course, a large Office establishment, and his head-quarters are with the Supreme Government. The patronage of all the higher grades of the Department in the Bengal Presidency is administered through this office, the minor appointments within the authorized number being left to the Local Governments. The minor presidencies of Madras and Bombay have also a similar official, who exercises the same duties in respect to his

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own Government and who corresponds with the Secretary to the Government of India on all matters involving Imperial control.

The Lieutenant-Governors of Bengal, the N. W. Provinces, and the Punjab, have each a Chief Engineer of the First Class for their respective Provinces, who is also a Secretary to the Local Government in his own Department, and corresponds with the Chief Secretary. Besides these, the Chief Commissioners of the Central Provinces, of British Burmah, Oudh, Mysore, Hyderabad, and the Straits' Settlements have each a Chief Engineer of the Second or Third Class, who is also the Local Public Works Secretary. These minor provinces, however, having no independent jurisdiction, have no patronage, which is administered by the Government of India; and the Chief Secretary addresses the head of the Government in person in his official correspondence, and not through his Local Secretary.

Besides the Chief Engineers of the regular branches of the Department, the Railway and Irrigation Departments in each Province have their Consulting or Chief Engineers, each of whom is also an Under Secretary to his own Government, and so communicates the orders of the Local Government to all concerned.

Under the Chief Engineers are two, three, or more Superintending Engineers, who are intended to be the eyes and ears of their Chiefs, maintaining a vigilant superintendence over all works in progress within their own circle of superintendence, and reporting to the Chief Engineer, who remains as a rule at head-quarters.

The Executive Engineers, as their name denotes, are those in actual executive charge of works, who are directly responsible for it, and for the expenditure incurred thereon; they are aided by a sufficient number of Assistant Engineers, who rise in their turn to the higher grades.

The Subordinate establishment of the Public Works Department includes Overseers (equivalent to Foremen or Inspectors) and who are generally Europeans; and Sub-Overseers, who exercises similar duties, and who are always Natives.

The *personnel* of the Engineer establishment, from the highest to the lowest grades is composed—1st, of Officers of the Corps of Royal Engineers; 2nd, of Officers of other branches of the Service,

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who have been regularly trained for the Department at the Civil Engineering Colleges or elsewhere; 3rd, of Civil Engineers sent out under covenant from England, of whom ten are now sent annually to this Presidency; 4th, of Civilians (English and Native) who have been trained at the Colleges at Roorkee, Madras or Calcutta. The Subordinate establishment consists—1st, of Soldiers from all branches of the service, who are trained at the Roorkee or Madras Colleges; and in Bombay of Soldiers drawn from the Sappers; 2nd, of Civilians, English and Native, who have been trained at College, or admitted as outsiders.

Besides the executive branches of the Department, there is also an Accounts' Branch, presided over by the Accountant General of the Public Works Department, who receives the orders of Government through the Public Works' Secretary, and under him are the Controllers of Accounts for the several Provinces, who have corresponding rank and pay with Superintending or Executive Engineers.

This branch of the Department has only recently been created, and is not yet entirely separated, as it should be, from the Executive Branch. The Controllers of Accounts correspond with the Executive Engineers, and the greater portion of the time of the latter is still taken up with *writing* about work instead of *doing* it. In time it is understood that responsible Accountants will be attached to all Executive Offices, so that the time of the Engineers and their Assistants may be exclusively given to their professional duties.

The general course of the business of the Department may be thus stated. The Financial Department of the Government of India having settled what portion of the available revenues* of the country shall be devoted to Public Works during the coming year, the gross sum thus apportioned is allotted by the Public Works Department to the several Governments in proportion to

* Besides the Imperial Revenues assigned for Public Works, certain Local Revenues in each District are also available for strictly Local Works; being derived from Octroi duties levied in towns, from Bridge and Ferry tolls, from a grant of 1 per cent. on the Land-tax of the district returned by the Imperial Government for Local Works, and from one or two other sources. Such Local Funds are expended under the direction of the Civil Authorities, on metalling local roads, paving and draining towns, planting trees, &c., and do not fall under the same rules as are applied to the Imperial Funds assigned for Public Works, being only partially subject to the control of the P. W. Department.

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their requirements, which have been previously ascertained by means of the preliminary Budgets sent in some time before. On the announcement of such allottment to any Local Government, the detailed Budget is submitted by that Government, showing in what manner it is proposed to spend the allotment, and final orders are passed in the Budget by the Government of India after a critical review of its contents. The several Budget headings, under one or other of which all expenditure must be classified are as follows :—

Class.	Departments.	Sub-divisions.
I. MILITARY.	A. ARMY.	1 Fortifications. 2 Cantonments. 3 Accommodations for Troops. 4 Ordnance. 5 Commissariat. 6 Stud. 7 Staff.
	B. NAVY.	*No Sub-Division.*
II. CIVIL ADMINISTRATION.	C. REVENUE.	1 Land and Miscellaneous. 2 Customs. 3 Salt. 4 Opium. 5 Post Office.
	D. GENERAL.	1. Government Houses and Residencies. 2 Public Departments. 3 Scientific Institutions. 4 Charitable ditto. 5 Monuments and Antiquities. 6 Miscellaneous.
	E. ECCLESIASTICAL.	1 Churches and other buildings. 2 Burying Grounds.
	F. EDUCATIONAL.	*No Sub-Division.*
	G. JUDICIAL.	1 Police. 2 Court Houses. 3 Jails.
III. PUBLIC IMPROVEMENT.	H. MUNICIPAL.	1 Town Buildings. 2 Markets. 3 Paving and Streets. 4 Lighting. 5 Water Supply. 6 Sewage.
	I. MARINE.	1 Harbours and Navigation. 2 Lighthouses.
	J. INDUSTRIAL.	1 Mines. 2 Manufactures.
	K. AGRICULTURAL.	1 Irrigation Canals. 2 Tanks. 3 Dykes. 4 Drainage. 5 Forests.
	L. COMMUNICATIONS.	1 Metalled Roads. 2 Unmetalled ditto. 3 Bridges. 4 Boat-bridges and Ferries. 5 Navigable Canals. 6 River Improvements. 7 Accommodation for Travellers. 8 Railways.*
	M. TELEGRAPH.	*No Sub-Division.*

All original works of any importance have to be entered in the Budget for the approval of Government, but the minor Presidencies

* This is intended for any Railways or Tramways made by Government. It has nothing to do with *guaranteed enterprise.*

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and Local Governments have power to sanction works not exceeding a certain sum,* while the Government of India must itself ask for authority from the Secretary of State for any work above a certain amount. No work whatever can be begun until the design and estimate have been prepared and approved by the proper authority, and no increase whatever can be made to permanent establishment without the direct authority of the Government of India in the Financial Department.

The amounts to be expended on the several works during the year are signified by each Local Government on receipt of the final Budget orders, to the Superintending and Executive Engineers, who have to regulate their expenditure accordingly, but the Government has certain discretionary powers as to the transfer of expenditure from one head of service to another if required. There is also a reserve which can be drawn upon for unforeseen contingencies.

So much for the business of the Department as traced from the fountain head *downwards*. The *upward* course of business has still to be noticed. An Executive Engineer, having with the help of his Assistants and Office establishment, drawn up his design, plans and estimate, for any particular work, either *proprio motu* or under instructions from his superiors, sends the project on to his Superintending Engineer, who may either return it calling for any needful explanation, or will send it on to his Chief with his own critical remarks. The Chief Engineer having further criticized it, will, as Secretary to Government, transmit the orders of the Lieutenant Governor or Chief Commissioner upon it, either negativing it, returning it for revision, or sending it on to the Supreme Government for sanction. If approved of there, it will then be sanctioned wholly or in part, and it will be ordered to be brought forward in the next Budget, under its own proper heading, so that funds may be assigned for its execution.

To complete this part of the subject then, it only remains to trace the progress of the work after sanction has been accorded to an Executive Engineer to proceed with it. Whether it is con-

* Madras and Bombay, Rs. 200,000; Bengal, N. W. Provinces, and Punjab Rs. 50,000; Oudh, Burmah and Mysore, and Central Provinces, Rs. 10,000.

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structed by contract or paid labor, he will have to render monthly accounts in prescribed forms of the progress of the work and the expenditure under each heading. These accounts are sent on to the Controller of the Province, and if nothing objectionable appears in them, they will be passed, the amount being struck out of the inefficient balance in the account current of the division. If the accounts are not in proper form, or if their total exceeds the sanctioned estimate, the Executive Engineer will have to render very exact explanations before he can get them passed.

Promotion in the Department from one grade to another goes partly by merit, partly by seniority. The names of those recommended by their superiors are annually submitted to the Government, and a selection is made from the lists to fill up vacancies, but the maximum number in each grade of each Province is strictly limited; so that a good man strongly recommended may often have to wait for some time. This of course is unavoidable.

Such is a brief sketch of the *personnel* and organization of this important Department. A few remarks may in conclusion be made in answer to the probable question, How does it work in practice? Before, however, we can answer that, it is necessary to offer a few observations for the benefit of the English reader. Let him then bear in mind that the business of the Department is vastly more extensive than that of any Board of Works in Europe, that it is the constructor and maintainer of nearly every mile of road and canal throughout the country, and of nearly every public building, whether Church, Barrack or Public Office, while it has also to exercise a control over the Railways, both during and after construction, far more complete and onerous than the powers wielded by the Board of Trade in England. Let him also remember that India is emphatically a poor country with a very unelastic revenue. From these considerations it results that money has to be doled out with a sparing hand after anxious consideration of the innumerable wants of the whole country—and that the Department has to bear the sins of every leaky building, every mile of bad road, and every broken bridge, in an empire as large as two-thirds of Europe. No wonder it is about the best abused Department in the country. It will,

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however, be seen from the above description that its organization is very complete; and where Public Works have to be constructed out of State revenues, their expenditure must be jealously scrutinized and controlled. This necessarily involves a delay not incidental to the transactions of a Joint Stock Company, with a large capital at its disposal raised for a specific object, and where the self interest of the Shareholders is the best guarantee for economy. If the want of capital, the multiplicity of its transactions and the heterogeneous composition of its establishment be taken into account in judging of the Department, it may fairly be said that the abuse so often heaped on it is very unjust, and that on the whole it does its work well.

If there be a fault, it is the common Indian one of over-centralization. A central controlling authority there must of course be, but it should be controlling only and not directing—and should only be concerned with general principles. A bureaucratic Government like that of India can only be successfully administered in any Department by choosing its servants wisely and giving them large powers. If unfit they should be removed, but their authority should not be subject to appeal or revision within its own limits. An attempt at minute control by an elaborate system of check and countercheck operates injuriously on subordinates in two ways—it makes them chafe and fret at the control, and it takes away largely from their sense of responsibility. It is better that a thing should be done wrong occasionally than that a good servant should be disgusted.

These principles are now being felt and acted upon. It is to be hoped that they may still further prevail—that Local Governments may have larger powers, greater discretion, and be held more fully responsible for the progressive improvement of their provinces; that private enterprize may be stimulated to undertake public works so that the expense and responsibility may not devolve entirely on the state; and that the weight of official correspondence, voluminous returns, and elaborate accounts may be still further reduced, so that men may have time to devote their best energies to the legitimate duties of their profession.

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No. CII.

THE CAWNPORE MEMORIAL.

The beautiful Memorial of the terrible Cawnpore tragedy of 1857, consists of a Gothic Screen of carved stone surrounding the Well; the well itself being surmounted by the colossal statue of an angel, the work of Baron Marochetti, and the gift of the late Lord Canning.

Over the gateway of the screen are the words, "*These be they who came out of great tribulation.*" Round the base of the pedestal over the well is the following inscription carved in Gothic letters—"*Sacred to the perpetual memory of a great co[illegible] of Christian people, chiefly women and children, who near this spot were cruelly massacred by the followers of the rebel, Nana Dhoondopunt of Bithoor, and cast, the dying with the dead, into the well below. July 15th, MDCCCLVII.*"

The screen stands in the midst of a pretty and well kept ornamental garden, the cost of garden and screen having been defrayed out of a fine levied on the native city of Cawnpore.

The screen was designed by Col. H. Yule, C.B., R.E., late Secretary to the Government of India in the Public Works Department.

The photographs given in the frontispiece were taken by Dr. Robotham, 7th Dragoon Guards, and by a native photographer at Lucknow.

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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.

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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.

Coorg is justly celebrated for its coffee. The planters have cleared

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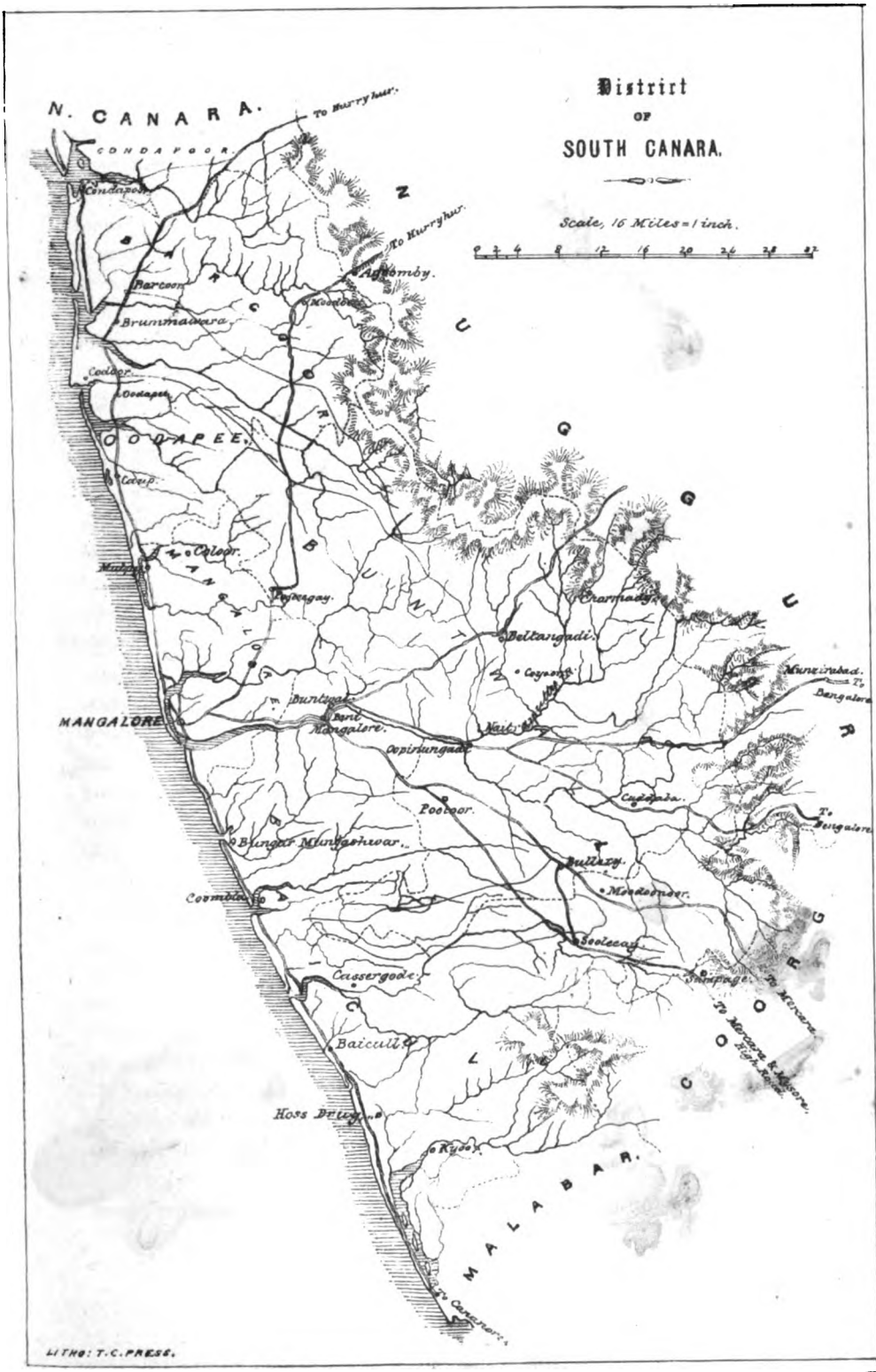

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numerous estates in the vicinity of nearly all the Ghaut roads constructed by the Government, both in South Canara and Malabar. Many settlers have selected Mercara as their field of operations, and every year transmit their crops to Mangalore by the 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

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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 repu-

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tation 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,

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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

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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

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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 Manny, 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.

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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

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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 being so often in the middle of large towns, the coffee estates of Coorg

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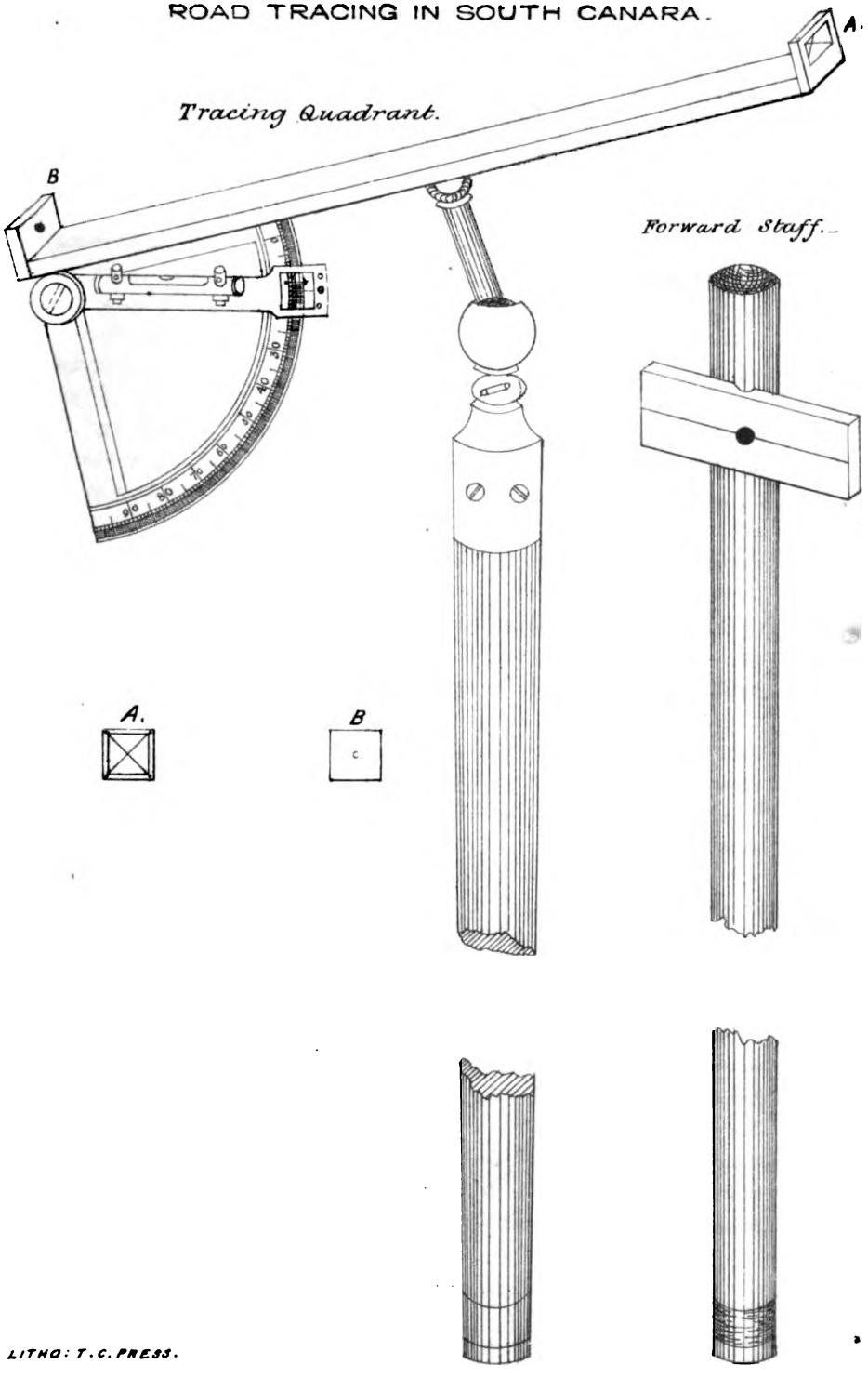
ROAD TRACING IN SOUTH CANARA.



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are in the main to be found flanking the Government roads. Although the land is of the same character all along the Ghauts between Mercara and Munzirabad, there being no Ghaut roads, there are of course no coffee estates. But with properties rising in value, the planters will soon begin to see the necessity of providing them, and as Government cannot afford to do what they ought to do for themselves, they must learn how to trace; and cannot do better than make themselves acquainted with that handy instrument the Quadrant. Sufficient skill to project a district road is not difficult to attain; and were a bridle-path opened by private enterprise, and its direction and gradients considered unexceptionable by an Inspecting Officer, a Government grant-in-aid could be applied for, to widen it out with a good chance of success.

Limestone occurs in Mysore, but not in South Canara. The lime for building purposes is obtained by burning shells or coral. The coral comes from the reefs in the neighbourhood of the Laccadive islands as ballast; though not hydraulic, the lime made from it is of fair quality and moderate in price.

Beasts of burden, such as horses and cattle, do not thrive in the district. The climate is too moist, and the grass is hard and innutritious. In consequence of this, for the conduct of large works, the Engineer has to purchase carts and bullocks, at from Rs. 90 to Rs. 120 for cart and pair, from the Mysore country. He should take this step without hesitation, as it is useless to rely upon hired carriage in a district where there is so much fever and rain. During the monsoon months the cattle can do but little work and may be let out to graze, and the cost of their keep must of course be provided for out of the estimates of the year.

Unskilled labor is tolerably abundant from November to March, but at the end of that month the people, especially if they have been drawn from a distance, evince an anxiety to get away to till their fields. In addition it begins to get very feverish near the Ghauts in April, and it is scarcely possible to carry on operations there in May. The monsoon bursts punctually about the 2nd or 3rd of June. Till the very day of its setting in, the sky is often clear, but heavy masses of cloud drift across the heavens for a week or so before. It generally breaks at the dead of night, when it hardly stops raining for a fortnight on end. There is then, a slight, but only a very partial, intermission, and it rains again steadily till the close of August. A gloomy haze overspreads the district, and narrows

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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).

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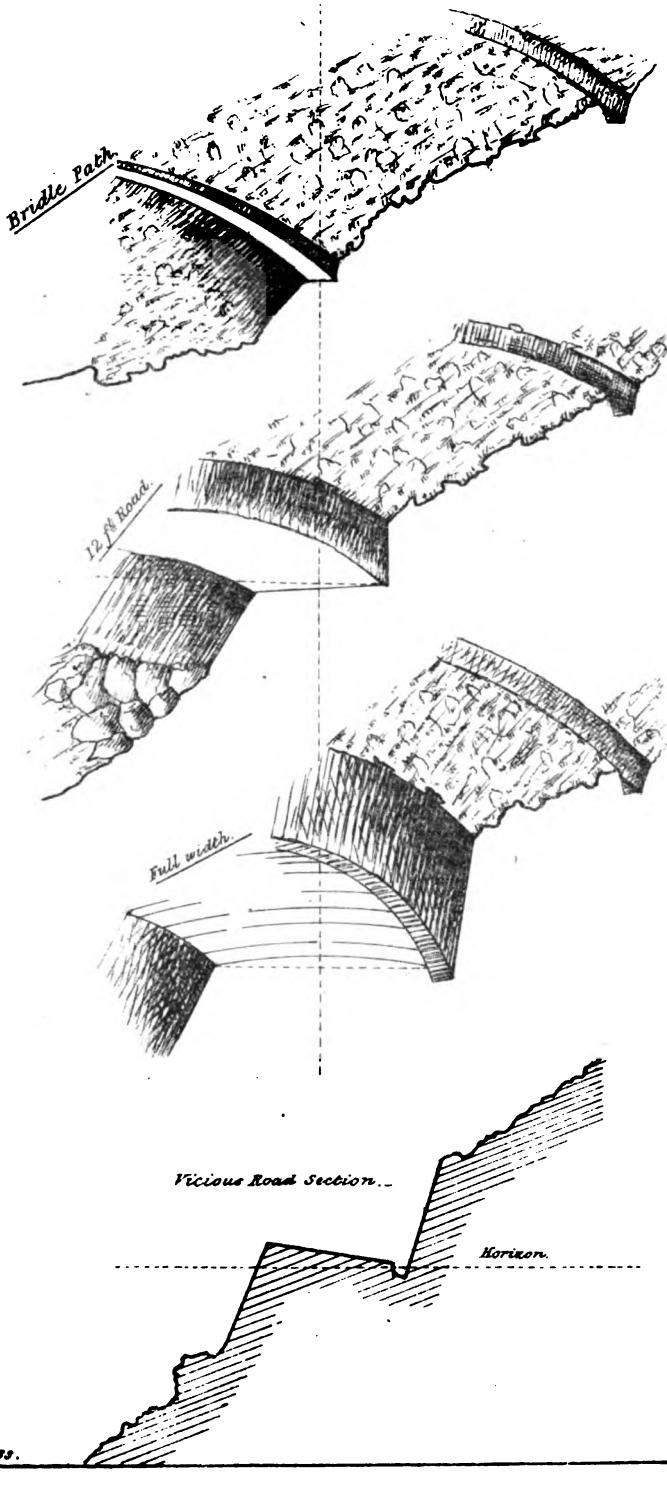
SECTIONS OF HILL ROADS.



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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

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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

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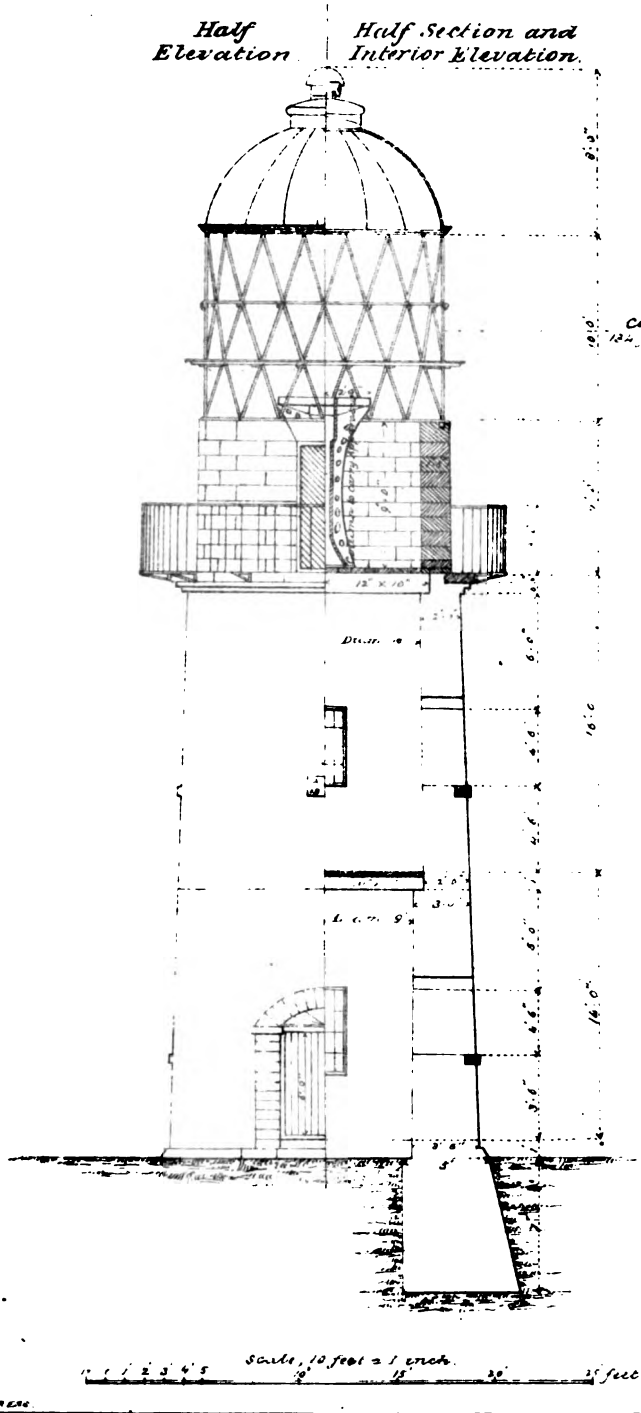
DOUBLE ISLAND LIGHTHOUSE.



LITHO. T. C. PREAS.

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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 3½ 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 18¾ nautical miles. The rise and fall at spring tides being about 20 feet, the above distance would at low water be increased to 19¾ nautical or 22¾ 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.

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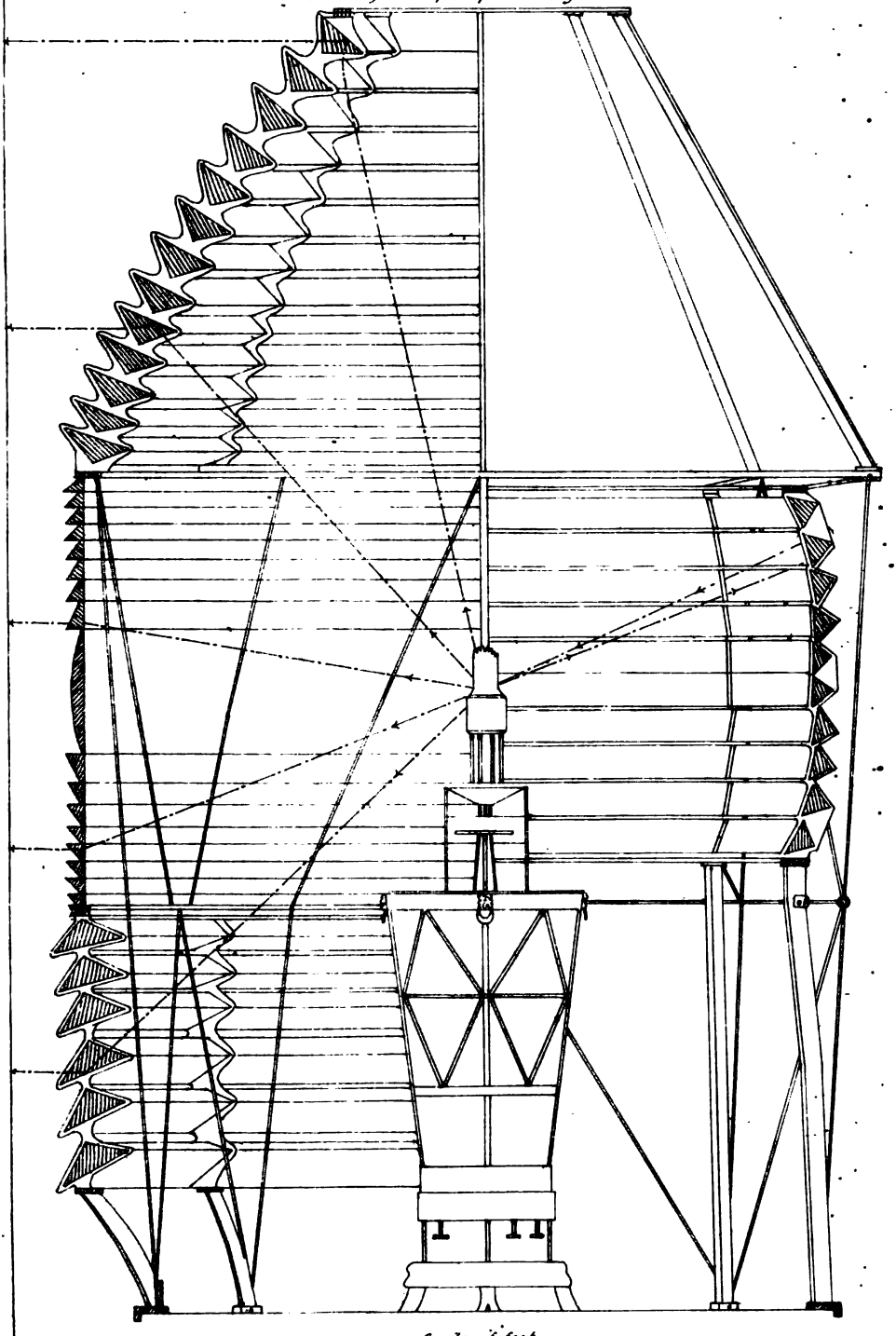
DOUBLE ISLAND LIGHTHOUSE.

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



Scale of feet.

12" 6" 0" 1 2 3 4 feet.

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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.

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