Cost of Manufacture.—The pipes were made up at Nanou in lengths of 2 feet, and 8½ and 6 inches in diameter; the expenditure upon them was as follows:—

	Rupees.
Manufacturing 7,800 pipes	704
Firing, including cost of loading and unloading kilns, .	525
Total,	1,229

The out-turn was:—

	No. of Tiles.	
1st class tiles, pucka, . . .	3,272	
2nd ditto, more or less peels, but still fit for use,	1,232	4,961
Broken or cracked, ...		2,839
Total,		7,800

From which it will be seen that the cost of each pipe turned out of the kiln was about four annas; but it may be confidently hoped, that as experience is gained, the cost will be greatly reduced.

The large proportion of cracked and broken pipes was caused by the frequent falling in of the arches over the flues, while the necessity for rebuilding them at each successive firing added greatly to the expense. This will be entirely avoided in the new form of kiln, a design for which is appended. Being greatly increased in height, it will admit of increased depth of flue and thickness of arch over it; the arches to the furnaces should be pointed, with a rise of 3 feet 6 inches in a span of 2 feet 6 inches; and by using fire-clay for cement instead of ordinary clay, there will be little fear of the arches giving way at the greatest heat to which the furnace will be subjected.

The tiles were made without sockets, as it was found they were not actually required, the joints being rendered prefectly water-tight by embedding them in lime. Sockets can be moulded on the tiles by hand before they are completely dried, and would prove of use in keeping the pipes in their respective places and preventing them from slipping, but in any case the lime must chiefly be depended on for a perfectly water-tight joint.

The great superiority of the pipes manufactured at Nanou over those turned out of ordinary tile making machines, consists in the pressure to which the clay is subjected during the process. When using firm clay (not over moist) it was found that the piston descended one-third of the depth of the cylinder before any clay escaped from the die, showing that the clay was compressed into two-thirds of its ordinary density. The united exer-

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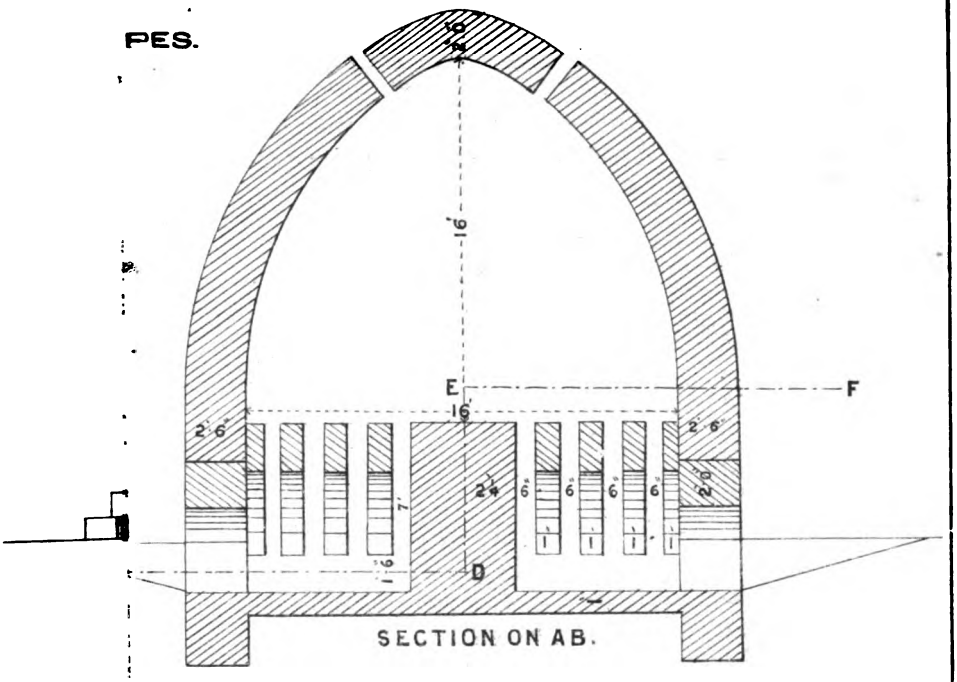
PES.



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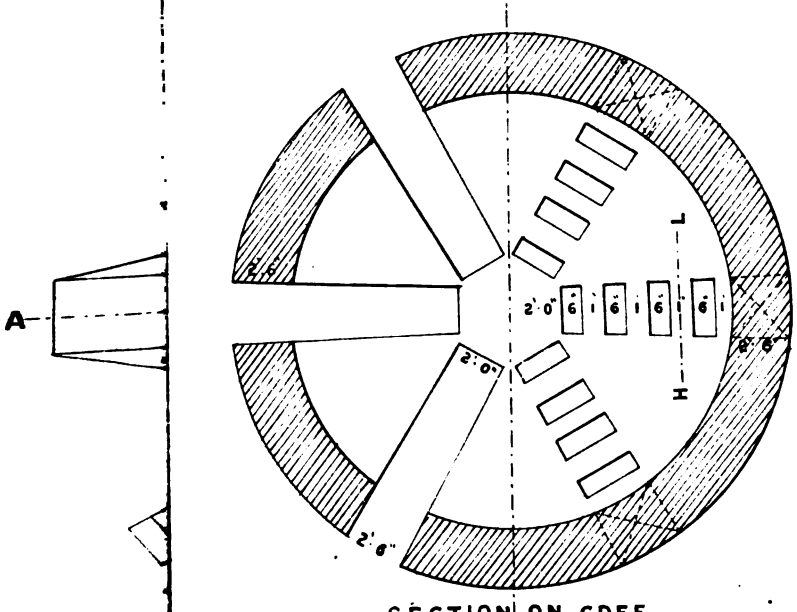

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UNIV OF MICH

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tions of 8 men were required to force the clay out of the die, producing a pressure on the clay of nearly 10 tons.

The last point for consideration is the size of pipe best adapted for irrigation outlets. This must in a great measure depend on the areas they are designed to irrigate, and the distance to which it is intended to carry the water. The sectional area of the *paimana* in use under the old contract system is ·4 of a foot, which was calculated by the late Colonel Baird Smith, to give under ordinary head pressure a discharge of 1 cubic foot per second. Although irrigation by contract has almost entirely disappeared, it was thought advisable to adopt this size as a standard in making our first pipes.

The sizes were accordingly fixed as follows:—

Large diam., ·708 feet, or 8½ inches nearly (sectional area, ·4 of a foot)
Small „ ·499 „ or 6 „ („ ·2 „)

A greater number of the smaller size were used, but in many cases they were found to furnish an inadequate supply of water. I am inclined to think that an intermediate size of 7½ inches (sectional area ·3 of a foot) would be the most generally useful. It would be as well however to have at least three different sizes, in order to meet the several circumstances under which they may be required.

The sizes proposed then for adoption are—

No 1. Diam. ·708 feet, or 8½ inches (sectional area, ·4 feet)
No 2. „ ·617 „ or 7½ „ („ ·3 „)
No 3. „ ·499 „ or 6 „ („ ·2 „)

W. J.

16*th January*, 1866.

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No. CXVII

ENGINEERING IN THE DERAJAT.

By the Editor.

The Deraját is the name given to a narrow strip of country lying to the west of the Indus, between that river and the Suleiman mountains, which form the boundary of our N. W. Frontier in that part of the Punjab; and is bounded by the Bunnoo District and the Sindh Frontier on the north and south sides, respectively. This tract of country includes two districts, those of Dera Ghazee Khan and Dera Ismael Khan, and measures 250 miles in extreme length, with a breadth varying from 15 to 50 miles, as the hills approach to, or recede from, the river.

The physical aspect of the country is peculiar. In the more southern district the river runs between low banks which are inundated during the rains, and whence canals have been cut conveying the water for some distance inland, to irrigate the autumn crops. In the cold weather the river falls and these canals are left dry, their beds being then cleared of the large quantities of silt carried in by the flood waters. But the soil is left rich and moist for the cold weather crop; well irrigation supplies the place of the canals, and a little rain usually falls about February. This part of the country is therefore well cultivated and fairly peopled.

But this description only implies to a small area. As we travel north, the river bank is so high that these inundation canals are impracticable; and again, as we leave the river and approach the hills, the level country soon disappears, and we meet a plateau rapidly sloping from their

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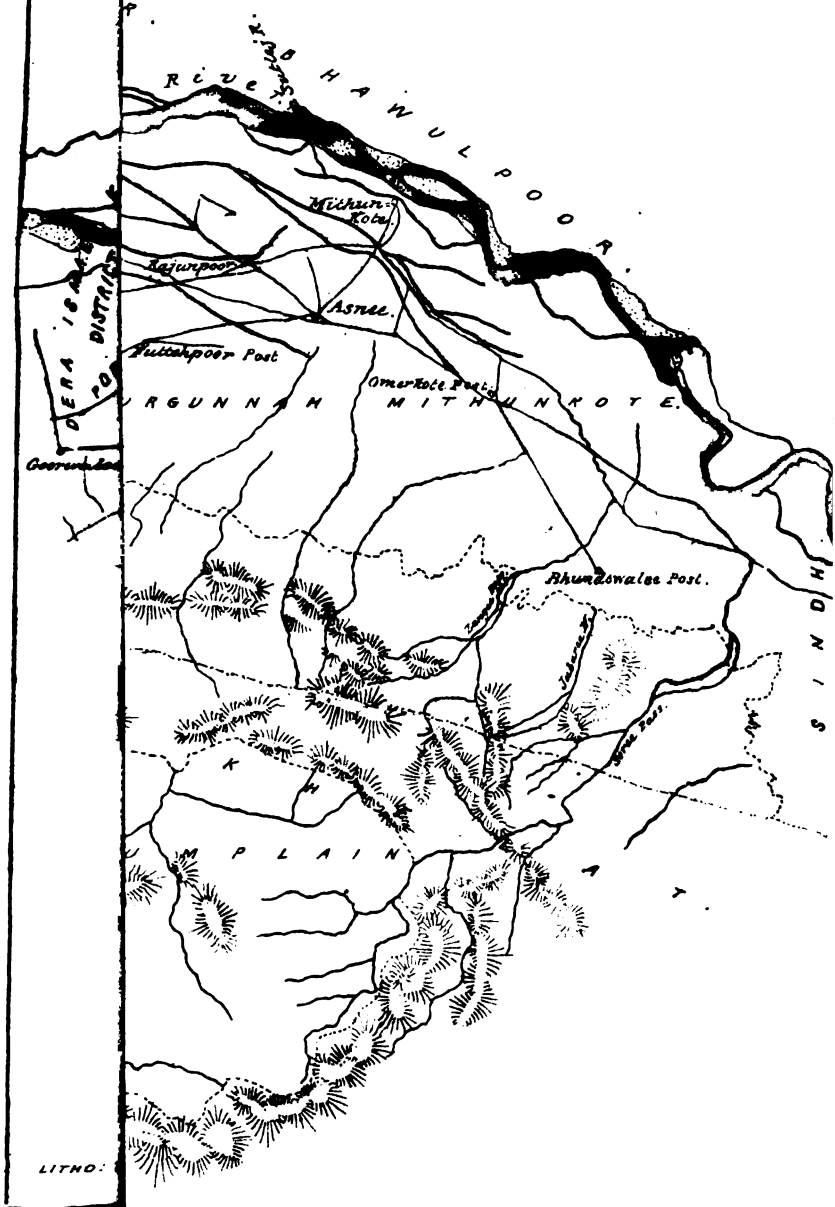
Map
OF
DISTRICT
DERAH GHAZEE KHAN.

The thick black lines show the Inundation Canals.



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foot until it meets the valley of the river.. The whole of this upland country forms a strange contrast to the lowlands near the Indus. The soil is a hard stiff clay, stoney near the hills and intersected by numerous dry torrents,—the climate is one of the dryest on the earth's surface, the annual fall of rain being probably about 5 inches,—and the wells are so deep ere the water-bearing stratum is reached, that their construction is expensive, and they can only be very partially used for irrigation.

The soil is too heavy for wheat, and a scanty crop of millet (jowar and bajra) is about the only thing produced. Villages are few and far between, and a coarse scrubby jungle takes the place of trees. The hills themselves are barren and desolate, but in their interior lie more promising valleys, nourished by occasional springs; and here resides a lawless population, who think cattle-lifting more respectable than agriculture, and are always ready for a raid into the plains through the mouths of one or other of the Passes.

A road runs parallel to this dangerous frontier at a short distance from it, and connecting a chain of military posts held by detachments of the Punjab Frontier Force. In support of these forts are the cantonments of Dera Ismael Khan, Dera Ghazee Khan, and Rajunpore, built in the more civilized country near the banks of the river.

For some years after its occupation by the British in 1849, the whole Trans-Indus country was a veritable *terra incognita* to the rest of the Punjab. No ladies were allowed to reside there—English soldiers were unknown, and as there was little to attract anybody in the way of sport, scenery, or antiquities, the country had very few visitors. But to those whose duties compelled than to reside there (among whom was the present writer), the very isolation of the country and the desolation of its aspect had something of a charm. The inhabitants were a fine, manly race, and there was so much to do in the way of physical improvement that the district was interesting enough to an Engineer. There was not a map of the country in existence, nor a mile of road, while the soil was either parching with thirst or being deluged with water. The irrigation canals which formed the very life blood of the district were unsurveyed and in bad order, while many had become choked with silt and had fallen into disuse—the water of the hill streams was turned to little or no account—and the lowlands were subject to severe inundations from the river. The population was scanty and laborers few; while the natives of other parts

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looked on the Trans-Indus region with dread, and could with difficulty be induced to cross the river. There was not a wheeled vehicle in the whole district, camels being the sole means of carriage.

The first thing to be done was to survey the country and prepare a tolerably correct Map, which was completed in the cold weather of 1853-54. The work was executed by means of polygonal traversing with the theodolite, the details being filled up by the prismatic compass and chain by means of Native surveyors. The map made no pretensions to scientific accuracy, but it showed with sufficient correctness, the course of the river, the lines of canals, and the positions of the principal towns and villages. The survey was necessarily bounded by the frontier road, as it was impossible to penetrate into the hills without an armed force.

The Canals being mapped, various projects were submitted for their extension and improvement, the objects kept in view being to straighten their course so as to lesson the sluggishness of their current and prevent the deposit of silt at the bends—to remove the spoil banks formed by successive clearances further back from the edge—and in several cases to provide new mouths instead of old ones abandoned by the river. It did not appear feasible to design head works of masonry, as such works might be rendered useless by a sudden shift of the deep channel of the river, and might themselves tend to cause such shifts by accumulating and attracting silt. The breadth of the valley of the river, and the consequent immense cost of the operation, prevented any idea of an *anicut* being entertained for the present, by which a perennial supply of water might be secured for the canals. Most of these projects and others allied to them in character, have since been gradually carried out by the present Executive Engineer (Mr. D. Kirwan), then the writer's Assistant, by which the prosperity and revenue of the district have been very greatly enhanced.

A system of forced labor existed for many years for the annual clearance of these canal channels in the cold season, whereby the zemindars were bound to contribute a certain number of workmen, requiting their services with food only. The Government contributed an equivalent in money, but took no cess for the use of the water which was free to all through whose lands it ran. This system has I believe since been modified.

The Hill Streams on which the scanty population at a distance from the river depended for whatever artificical irrigation they had, varied much in

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size and section of channel. From two only, small perennial streams flowed, and it was curious to see how under the magic influence of these insignificant rivulets, villages had sprung up, smiling harvests waved and trees nestled to their banks; these oases in the desert serving to show that want of water alone prevented the whole district from being a fruitful garden. But the casual torrents of water in the (otherwise) dry hill streams were carefully turned to account. Dams of earth, stones and brushwood, were thrown across their dry channels in readiness for the possible rain, and irrigating channels carefully led from above their sites to the surrounding fields. The furious torrent might burst these flowing barriers in an hour or less; but that short delay had sufficed to turn a supply of water into the dry channels, and below the first dam, a second, third, or fourth was ready to detain the impatient water, and compel it in like manner to leave a portion of its volume for the irrigation of the thirsty soil. Often in this dry climate was the headstrong but welcome guest looked and waited for in vain, while the seed already sown withered and died; not seldom did it come down with such irresistible fury, that dam after dam was swept away too quickly for any portion of the precious fluid to be secured. The sites and strength of these dams had been settled by custom and ancient prescription for many years, and attempts on the part of any zemindar to erect new ones, or render the upper ones unduly strong, led to fierce affray and bloodshed, often terminating in loss of life.

Some of the most promising of these torrents were surveyed, and designs submitted for storing up the water in a more systematic manner, either in tanks formed by damming up the gorges of the passes, or by permanent dams in the streams themselves, thus forming a series of still water reaches at different levels. These were recommended to the notice of Government as experiments well deserving a trial, but the troubles of the Mutiny came on, the writer had to leave for the seat of war, and the projects have, I believe, since been in abeyance.

So complete was the absence of Roads in the district, that the troops marching down in the relief of 1852, had to take guides with them on (what should have been) the main line of road,—and the country was too poor to afford the expensive embanked roads that would have been required over the greater portion of its extent. But a commencement was at least made, and in conjunction with the civil authorities, a system of roads was

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designed and proper alignments chosen, which should be gradually worked up to as funds were available. This system comprised—1st, A main line of road running the whole length of the two districts, from their northern boundary to that of Sindh on the south, generally parallel to the river, and to the frontier military road near the hills. This line passed through the principal towns, and was chosen so as to ensure halting places for travellers at convenient distances; 2nd, A series of cross roads connecting the Frontier, with the main district, road, at places of the most consequence on each. These roads were laid out from the map, or by means of special traverses made from place to place; they were then cleared for a breadth of 20 or 30 feet, and inequalities of surface tolerably levelled, while temporary wooden bridges were made over the canals. Where the jungle was very thick it was cleared for some distance on both sides of the road. As money was not forthcoming to raise these lines clear of inundation, many of them were annually flooded and repaired immediately after the subsidence of the river. For the passage of the dry hill torrents, the sides were sloped down and paved causeways in some cases substituted as a cheap and efficient makeshift in lieu of bridges, which would have been practically not required for more than perhaps ten days in the whole year.

The Military Forts on the Frontier* were from 10 to 16 miles apart, and consisted generally of a square redoubt enclosed with a mud wall and ditch, and containing barracks for the native soldiers. In one corner was a high square tower which could be isolated from the rest and served as a Keep, to be held if necessary by half a dozen men; it contained the magazine, provisions and water for the garrison. The largest forts were 85 yards square, and were garrisoned by 40 sowars and 20 infantry; the smaller were 50 yards square, and were meant for 25 sabres and 12 bayonets; no artillery was mounted in any of them. The wells in these forts from which the supply of water is derived, are often of great depth; one, a very old well, measuring not less than 220 feet to the water's surface, and another 150 feet. The water of the latter has so bitter a taste that horses will not at first touch it, and this is a characteristic of many wells in this part of the country. I have seen three in a row containing sweet water, and three in another row, scarce 200 yards nearer to the Hills, whose water, though clear as crystal, had a strong saline flavor.

The Deraját contains three small Cantonments, from which the frontier

* See the Koorum Frontier Out-post, No. 8 of these papers.

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garrisons are supported and relieved; Dera Ismael Khan on the river's bank to the north; Dera Ghazee Khan, also on the river, 120 miles lower down; and Rajunpore, 70 miles still lower, and some few miles inland. The barracks and private houses are generally built of sun-dried brick, which lasts well in so dry a climate; while burnt bricks are expensive, owing to the cost of fuel.

The River Indus, which forms the boundary of these districts to the east, is here a broad, shifting stream, with a sandy bed. The general slope of the bed is about 1 foot per mile, and the minimum cold weather discharge as taken a little above Dera Ghazee Khan is about 14,000 cubic feet per second. At Mittunkote, 70 miles lower down, is the junction of the Punjnud, which contains the united waters of the Sutlej, Beas, Ravee, Chenab and Jhelum. The place, one would think, should be of considerable importance, but Mittunkote is a very small town, or rather was so, for it has since been swept away by the river. The navigation of all these streams is difficult and precarious, owing to the constant shifting of the deep channel, and the districts through which they all flow are poor and thinly populated. Steamers however now go up to Kalabagh, the first rapids where the Indus breaks through the Salt Range, but the bulk of the traffic (which after all is small) is carried in native flat bottomed boats of from 400 to 1000 maunds. A strong south wind blows pretty steadily during the hot weather, greatly assisting the up-stream navigation at that time; in the cold weather there is nothing for it but tracking.

Besides shifting its course and throwing up sandbanks year after year, the river also cuts away its banks very much, and has swept away many a village, and more than one town in this manner. Dera Ismael Khan was seriously threatened about five years ago, and a very interesting series of works was carried out by the Executive Engineer (Mr. Hubert Garbett), which has had the desired effect of diverting the set of the stream, and for the time at least has saved the town and station. Wherever the banks are low, which is the case generally below Dera Ghazee Khan, they are inundated by the river in the rains for a width of a mile or more, the water being checked from further advance by the high canal banks or earthen dams specially constructed. The inundated land is however covered with a rich deposit of silt, and bears abundant wheat crops in the cold season.

A more serious and extensive Inundation however had established itself annually at the time of my arrival in the district, which required some

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Engineering skill, and a very heavy expenditure to deal with properly. Twenty miles above Dera Ghazee Khan the river had made a set inland, and a considerable body of water passed through the heart of the district, and interposing between the town and the hills, held a course of 60 miles in length before it rejoined the main stream. The cantonment was not only isolated from the military posts that it had to support, and only saved from destruction by two canal banks which had been repaired and strengthened; but some 500 square miles of the best land of the district was swamped, while the destruction of villages, crops and cattle was very serious—the remissions of Government revenue in one year amounting to Rs. 28,000. It seemed probable too that unless checked, the action of the water would form for itself a regular channel, and the whole of the Indus might take the same course.

Having taken the necessary surveys, and carefully inspected the site, both during and after the flood, a project was accordingly submitted and duly sanctioned. It did not seem likely that any operations on the river with a view of diverting its course would be effectual; they would at least have required to have been continued for several years—they would have cost a large sum of money, and the result would after all have been doubtful. It seemed better, in presence of the immediate and increasing danger, to carry an earthen embankment across the mouth of the inundation, so as to shut it out and turn it back at the site of its exit. The difficulties attending this were the limited time and labor available for the work—the danger of the river's cutting away its bank and eating up to the toe of the bund; while, if carried too far inland, the water in its descent into the valley would accumulate in force and depth—the necessity of crossing two canals without interrupting irrigation and the danger of attack from hill streams in the rear. Nor did any one of these dangers prove imaginary.

The project having been sanctioned, no time was lost in carrying it out. A thousand laborers were imported on monthly wages from Hindustan and the Punjab, and the Civil Officer lent assistance in collecting labor from the district. In raising the embankment much use was made of a simple machine called the *khen*, or scoop, which is also employed for the same purpose in America. It consists simply of a piece of board about 5 × 3 feet, made slightly concave, with a handle on the upper edge, and attached at the two sides by ropes to two bullocks. The ground being first loosened by the common plough, the lower edge of the *khen* is pressed into

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the soil by the driver's weight, and the bullocks then drag the earth so collected to the side of the bund, where by simply turning over the *khen* on its edge, the earth is deposited.

The length of the embankment was 12 miles, and it varied in height from 1 to 10, or 12 feet; the width at the top was 5 feet; the slope on the water side only 2 to 1; it should have been much more. No turf was available to protect it, and the soil in many parts was a stiff clay liable to crack; all that could be done to consolidate it was to ram it carefully, layer by layer. The two intervening canals were crossed by masonry sluices, the piers of which were built upon wells in the usual way.

The work was barely finished before the river rose, and aided by a strong wind breached it in several places. One or two of the breaches were successfully closed, but the force of the water prevented it in most cases, and all that could be done was to defend the broken ends by spurs and brushwood piling, which was done very successfully, so as to render the amount carried away a minimum. In spite of the breaches, eleven in number, the benefit caused by the embankment was very sensible, the extent of the inundation having been very much lessened. In the following cold weather therefore, the breaches were closed and the whole work strengthened, and the first rise of the river was successfully kept out. In August, 1856, however, heavy and continuous rain caused an inundation higher than had been known for very many years; and which at the same time brought down the hill streams in torrents from the rear. Thus attacked in front and rear, the bund was again breached in several places, and the force of the inundation was so great that part of the cantonment of Dera Ghazee Khan was swept away, and the city itself flooded. For three days the whole population was cooped up in the fort, which was built on very high ground, where they remained until the waters subsided. Communication with the frontier forts was completely cut off, and the loss of property and even life was heavy—the villagers had in many places to take temporary shelter in the date trees where they constructed *machans*, and remained there until boats were sent to take them off. Very extensive repairs were needed at the embankment; and, fortunately, the inundation during the following year being lower than usual, gave the new work time to consolidate. Since then the work has stood well, and has effectually answered the purpose for which it was designed. The total cost was rather more than a lakh.

One or two practical lessons were learnt during this contest with the

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river, which it may be useful to record for others in similar cases. The great difficulty of all such works consists in the want of time for the new earth to consolidate before being attacked. No artificial means are so effective as natural consolidation, but it is possible to some extent to lessen the danger. The water-slope should be laid out at an inclination of *at least* 4 to 1: and it is worth going to a very considerable expense to defend this slope artificially. Grass is often not available; or, if at hand, it will not grow at all in some soils; nor in any, without being watered at first, which is often very expensive. It is, however, the very best protection to the slope; but where not available, twisted grass ropes, as used in Holland, laid in long pieces and pegged down, are good, and are generally procurable; or large coarse mats may be employed. Such materials will of course not last more than one season, but that is really all that is wanted. By that time, if there has been a little rain, the earth will have consolidated sufficiently to defy the water unless the bund is over-topped.

Of Engineering materials the Deraját possesses excellent lime, burnt from the limestone boulders found in the dry beds of the hill torrents. Good building stone is doubtless also procurable there, but the carriage is too expensive. Earth for bricks is plentiful enough but fuel is dear and bad. Wood is very scarce, two or three kinds of jungle timber are alone available in the district itself, but deodar and cheer are floated down the Indus or Jhelum from the Himalayas. Labor, both skilled and unskilled, is scarce; good workmen must be imported from the Punjab at high wages. There is a peculiar class of men, called *Odhes*, who migrate from place to place seeking work as beldars; they are excellent workmen, and very willing to take petty contracts; they are, I believe, emigrants from Hindustan. Carriage there is (or was) none available, except camels and a few pack bullocks or donkeys.

Years must probably elapse before the country of which I have been speaking can be rich or populous; but much progress has lately been made—old canals have been opened out, new ones dug, population has increased, the border is quiet, and in short the ordinary results of a few years of British rule are apparent. Much yet remains to be done however—in storing up the hill water—in guarding against the encroachments of the river—in still further improving the canals—and to the young Engineer, fond of his profession, it will for a long time remain one of the most interesting districts of the Punjab.

J. G. M.

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No. CXVIII.

BRIDGE FOUNDATIONS IN SANDY RIVERS.

By R. G. Elwes, Esq., C.E., *Executive Engineer.*

It is proposed in the following paper to give some account of a discussion relating to the foundations of the Markunda Bridge, (near Umballa in the Punjab,) which has extended over several years, and will it is thought, be of general interest. It is hoped also, that the Madras Engineers may be induced to give the results of their experience upon the points raised.

A description of the Markunda river, with drawings of the bridge, as it is now being constructed, will be found in a former volume of these Papers (Vol. I., page 442).

The main point at issue is whether, in rivers with sandy beds of unknown depth and considerable slopes, it is on the whole preferable to carry down the foundations to such a depth that no danger need be feared from scour, (sufficient waterway of course being allowed,) without further protection; or, to make the foundations comparatively shallow, and to obviate the danger of scour by floorings or inverts, curtain walls, aprons of boulders or crib work, and similar means. For the sake of brevity the former plan will be spoken of as that of "deep," and the latter of "shallow" foundations.

The Markunda river rises in the Nahun or Sirmoor territory; it is subject to sudden and violent floods, which overflow the country for miles on either side. The bed is pure sand, or sand mixed with equally friable silt, to an unknown depth. Its declivity where it crosses the Grand Trunk Road is 2·72 feet per mile; and the highest *known* flood

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discharge, about 50,000 cubic feet per second, with a depth of 10 feet, and a velocity of about 5 feet per second. A more detailed description of the river is given in the paper above referred to.

The first design for bridging the Markunda river, of which I can find any account, appears to have been drawn up by Lieut. (now Major) Chesney, R.E., and submitted by Capt. Grindall, Executive Engineer of the Grand Trunk Road, in 1856. The design was for an arched bridge of brick, the arches 36 feet span, the foundations of piers and abutments resting on blocks 20 feet deep, and further secured by curtain walls of blocks above and below the bridge, which were also to be 20 feet deep. Between these curtain walls there was to be a continuous flooring. The foundations for one bay of the bridge upon this design were executed, and have been made use of in the present structure, as will be seen by referring to the plan at page 442, Vol. I.

It seems to have been expected that at a depth of 20 feet, a good stratum of clay would be found, but subsequent trials showed that the bed consisted of nothing but sand, and a mixture of sand and silt, to a depth of more than 40 feet. A few local patches of clay have been come across in the execution of the work, one of which probably misled those who made the original boring.

In forwarding the design, Major Laughton, R.E., then Superintending Engineer, proposed to omit the curtains and flooring altogether, and to carry the foundations down to 40 feet. He objected to the curtains; first, because in order to be safe, they must be carried down to such a depth, that it would be cheaper and simpler to make the pier foundations themselves deep enough to be safe: and also, because the water would be likely to find its way between the blocks, wash out the sand, and so cause the floor to fall in. This prediction, it will be seen further on, has been exactly verified.

Colonel Hugh Fraser, R.E., then Chief Engineer of the Punjab, seems to have concurred in Major Laughton's views; but I have not been able to find his opinion on record.

Colonel W. E. Baker, R.E., then Secretary to the Goverment of India, however joined issue, and in a letter dated December 26th, 1856, to the address of Sir John Lawrence, K.C.B., he makes the following observations:—

"The value of curtain walls and the security of floors protected by

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them are well ascertained facts. To go no further, the Solani aqueduct is an instance in which both have been adopted, and have stood exceedingly heavy floods.*

"It is indeed precisely in great floods that these adjuncts to a bridge are so important. The irregular action of the current on the river bed at such times is the great difficulty with which Indian Engineers have to deal. It by no means follows that the action of the stream must always extend to such depths as 30 or 40 feet, but that where the protection of floors is not sought, circumstances which are then beyond the control of the Engineer may cause disturbances of the lower bed such as are spoken of.

"It will be a matter for consideration in each particular case, which is the best plan to follow; whether we should carry the depth of the foundations beyond the possible action of the floods, or whether we should protect the bed of the river in the vicinity of the piers by a floor and curtain walls."

Colonel Baker then proceeds to point out "the success which has attended the construction of the great dams or anicuts across the rivers of Southern India on foundations which rest on mere sand, and only go to a depth of 6 or 8 feet." He proceeds: "It is of course not to be understood that such small depths are suitable as a matter of course for bridge foundations in all rivers, but only that there are circumstances under which very moderate depths are sufficient, and that a careful consideration of every element is requisite before coming to any decision on such questions." To this letter were attached some extracts from Colonel Baird Smith's Work on Irrigation in Southern India, which it will be more convenient to give further on.

Shortly after Colonel Baker's letter was written, the mutiny broke out, and the Markunda bridge project remained in abeyance until 1859, when Mr. C. T. Campbell, C.E., who had been in charge of the Tonse bridge while in the service of the E. I. Railway Company, was appointed to re-examine the whole question. He submitted plans and estimates for four alternative designs, viz:—

1. Brick bridge, arches 80 feet span, on block foundations 40 feet deep.
2. Iron Wire Suspension bridge, on brick piers, one span of 500 feet, and two of 250 each.

* I believe the Solani curtains are blocks 20 feet deep, the intervals filled in with piles to the full depth. The importance of thus stopping up the intervals will appear presently.—R. G. E.

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3. Cast-iron Girder bridge, spans 30 feet, on screw piles and cast-iron columns.
4. Iron Wire Suspension bridge, same as No. 2, but the piers formed of eight cast-iron columns, resting on cast-iron screwpiles, 2 feet in diameter.

In the elaborate and valuable report, dated January 1st, 1860, which accompanied these designs, Mr. Campbell strongly advocated the last, on the grounds of economy and minimum obstruction to waterway. In discussing the design for a brick bridge, he gives the following reasons for rejecting the flooring and curtain system. After observing that he proposes to omit these adjuncts, and to trust entirely to depth of foundations for the safety of the bridge, he proceeds:—

"Without for one moment questioning the well ascertained advantages attendant, in many cases, on the use of curtain walls and paved floorings, it may perhaps be doubted whether they would be so advantageous as blocks sunk to a depth beyond the action of the floods in such a torrent as the Markunda, rising so rapidly and tearing along with such force and violence. It must be remembered that it often brings down with it large trees, which, in an arched bridge, will be very apt to accumulate in one or more of the openings, obstructing them and causing the water to rush with redoubled force through the other arches. In such a case scour must ensue, and if it cannot have effect between the piers, it will cut above and below the curtain walls. Such instances I have seen occur before, on a small scale it is true, but still the rule will apply here too; and I have seen in a 15-feet culvert, founded on sandy soil, water, brought to a head by obstructions in the arch, force its way *under* a deep apron and *through* the joints of an invert, the mortar in which was well set. Had the invert been a flat paving it would probably have been blown up.

"Such an event might occur here, the water finding its way under and between the curtain blocks, blowing up and sweeping away the pavings; scour would ensue, and before anything could be done to stay it, the curtain blocks might be overturned, one or more piers undermined, and the whole bridge thrown down. This is of course an extreme view of the case, but it is precisely such views that must be taken into account in deciding a question of this nature."

Mr. Campbell's arguments, however, failed to convince the Government of India. Colonel Yule, R.E., then Secretary to that Government, in a letter

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dated May 20th, 1861, while acknowledging the care and labor bestowed upon the designs, preferred a modification of the original one to any of them. It was directed that the arches should be made from 37 to 40 feet span, so as to bring into use, if possible, the portion of work already executed. With regard to the foundations, Colonel Yule made the following remarks:—

"Well foundations may be used in two ways, viz., either by employing the wells as piles and sinking them till we reach a firm stratum; or where such a stratum lies very deep (as in the present case), by establishing a practically impermeable barrier under the bridge in the shape of flooring and curtain walls, to secure the foundations from scour. The last method has often been used on this side of India, (without, it is believed, a serious example of failure,) but it has never been so fully taken advantage of as in the Madras Presidency. There, as has before been precisely pointed out in correspondence on this very subject, well foundations of bridges, in sandy beds of unknown depth, are not sunk more than 9 or 10 feet, often less; the wells themselves being also of very rough and crude structure. Yet they stand safely; and it is mainly owing to the cheapness of this construction that so many noble bridges have been built in the Madras Presidency, over rivers such as we habitually leave unbridged, on account of the estimated cost. Indeed, the experience of Madras shows that well foundations of 6 feet in depth, on sandy river beds having a slope of 3½ feet per mile are secure.

"It is not necessary to go to such an extreme, in order to secure the advantages of a desirable economy. In revising the design, the depth of the pier foundations should be limited to 15 feet, and that of the curtains to 12. Round wells should be used instead of square blocks. They are more easily and rapidly sunk, and are just as good for the purpose now in question. But in the upper curtain wall the greater continuity of long rectangular blocks will be an advantage. The curtains should be kept well clear of the cut-waters of the piers."

Upon these instructions, the design given in Vol. I. of these papers, was prepared by Mr. W. Purdon, M. Inst. C.E., who had been appointed to the charge of the works. Round wells were used in the upper as well as in the lower curtain wall; in consequence of a difficulty in procuring wood suitable for block *neemchucks*. In the lower curtain, continuity was sought to be obtained by putting down two rows of wells, those in the second row being

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placed opposite the interstices of the first. The works were commenced in 1861, and up to the beginning of 1865, nothing occurred to throw doubt upon the security of the plan adopted, so far as the curtains were concerned.

In consequence, however, of the ease with which the pier wells were countersunk to the prescribed depth, it was thought desirable to sink them somewhat further, lest they should be unable to bear the weight resting upon them. It will be seen on referring to the drawings, that each pier rests on ten wells of 5 feet diameter, giving a wide base* independently of the concrete between the wells; but it was thought possible that the semifluid sand might yield lightly to the pressure, and so endanger the arches. The Government of India, in discussing the Executive Engineer's proposal to sink the pier wells to 20 feet, observed as follows :—

"They (the pier wells) were, as settled by the Government of India, to be only 15 feet deep, instead of being sunk as usual in the N. W. Provinces, until they will descend no further. This small depth, when combined with a well protected flooring has been proved by Madras experience to be perfectly reliable, and it was considered an object to have an example on this side of India. Accordingly, the order was issued, and the wells have been got down to that depth; but with such ease, it is stated, that a further depth of 5 feet, considered 'wiser because safer,' has been ordered.

"Bearing in mind that works on wells only 6 feet deep, have succeeded in Madras in rivers with sandy beds, sloping 3½ feet per mile, a safe margin for the experiment was allowed, in ordering wells 15 feet deep in sand, the slope being certainly under 4 feet per mile.

"The Executive Engineer suggested this greater depth of 15 feet, because† he deemed that the river channel being contracted by the contemplated bund and the bridge piers, there may, in a flood, be a scour of from 5 to 8 feet of the silt deposited on, or rather forming the upper stratum of the bed. But if a scour takes place and foundations be endangered, the curtain wells will certainly be affected before the pier wells are. If the curtains go, the flooring also will go, and the pier foundations will then be exposed to an action they were never intended to, and certainly would not, withstand. * * * * * * *

* The pressure on each square foot of the wells supporting the piers, including the "hearting" of concrete is 3 tons.

† The chief reason seems to have been the doubt as to the bearing power of the wells in soft sand as noted above. The bund referred to has not been executed as yet, and will not contract the waterway.—R. G. H.

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so that if 20 feet depth of well is necessary anywhere, it is in the curtain wells, which protect the remainder.

"It has not been overlooked that the depth of the curtain wells originally ordered, compared with that of the pier wells, is open to condemnation on the grounds now laid down, and it may with advantage be noted that in Madras, the bed of the river would in most cases, be protected to a greater distance below the bridge than 14 feet, whilst there is generally plenty of stone at hand for tail protection there."

By the time these orders reached the Executive Engineer, one row of curtain wells had, I believe, been sunk to 12 feet and filled in. They could not therefore be lowered; the greater part of the pier wells also had been sunk to 15 feet; and had stood for a rainy season. Upon recommencing work, it was found that they had become so earth bound that they could scarcely be moved; and thus, while the intention of sinking them to 20 feet was frustrated, the necessity for doing so was proved not to exist. Difficulty was found in getting even new wells down to 20 feet, and eventually the pier wells were left at various depths, according to the resistance experienced, from 15 to 20 feet.

It has been mentioned that only one row of curtain wells on the lower side were put in at first. From motives of economy, the second row was deferred, but unfortunately, the necessity of taking other precautions, such as piling between the wells, to make the single row a really impervious barrier, does not appear to have been sufficiently foreseen. The spaces between the wells were intended to be filled to a depth of 5 feet, with 3 feet of concrete, and 2 feet of masonry. From the high level of the water in the bed, or some other reason, it seems to have been impracticable to put this protection to its full depth at all points: in some places it was found to be only 3 feet, or even less.

The piers had all been built before the rains of 1864, and now the effect of the bridge in producing a scour of the bed might be expected to become visible. A gradual deepening of the channel had been taking place since 1859, when the zero of the gauge (the level of the flooring) was 2 feet below the lowest point in the bed of the river. In 1864, the lowest point of the bed was almost level with the zero, but in that year the highest flood was only 7·5 feet, the waterway was clear, and the state of the bed favorable. No scour was observed.

It must be remarked here, that the effects of a flood in the Markunda

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depend rather upon the suddenness with which the waters come down, and the state in which they find the bed, than upon the extreme height to which they rise. The channel is a wide shallow shifting bed, constantly getting choked by heaps of drift sand and banks of silt, which are sometimes thrown up to a height of 5 or 6 feet by a single flood, a corresponding encroachment taking place on some other part of the bank. The floods occasionally come down with extreme suddenness, so that people overtaken in the dry bed of the river are drowned before they can reach the bank. One flood had reached a height of 5 feet upon the flooring, which had previously been quite dry, in almost five minutes from the appearance of the first trickling stream.

In the spring of 1865, shortly after I took over charge from Mr. Purdon, who was removed to a higher appointment, a winter flood of about 4 feet came down, and being slightly obstructed by the masonry piers which supported the centerings on one side, and by large deposits of silt on the other, scooped out a hole about 4 feet deep (probably much deeper during the height of the flood) immediately below the curtain wall opposite two of the arches. Some sand was washed out between the curtain wells, which are 15 inches apart, and the connecting portion of concrete and masonry, which happened to be only 3 feet deep at this point, fell in. The edge of the flooring was taken up, but the injury did not appear to extend beyond the back of the curtain wells. The hole was filled up with concrete and masonry; and to protect the green work during the rains, a row of sheet piling was driven about 10 feet from the edge of the flooring in front of the two bays where the scour had occurred, secured by waling pieces to guide piles 12 feet deep. This protected the place for the time, but the accident set me thinking what would be the effect of a maximum flood of 10 feet in depth coming down suddenly, with the channel so blocked up with silt as it usually is. The section attached, taken 500 feet above the bridge, shows the state of the bed in February, 1866. The average depth of silt is $4\frac{3}{4}$ feet, and the area of waterway between the bed of the river, the abutments, and the springing line, 12 feet above the flooring, is only 9,041 superficial feet, which with the normal velocity of 5·5 feet per second, gives a discharge of 49,725 cubic feet. Now, a flood rising only to 10 feet above the flooring requires a discharge of very nearly 50,000 cubic feet. It was evident, therefore, that there must be a great heading up of the water at the bridge, until the river

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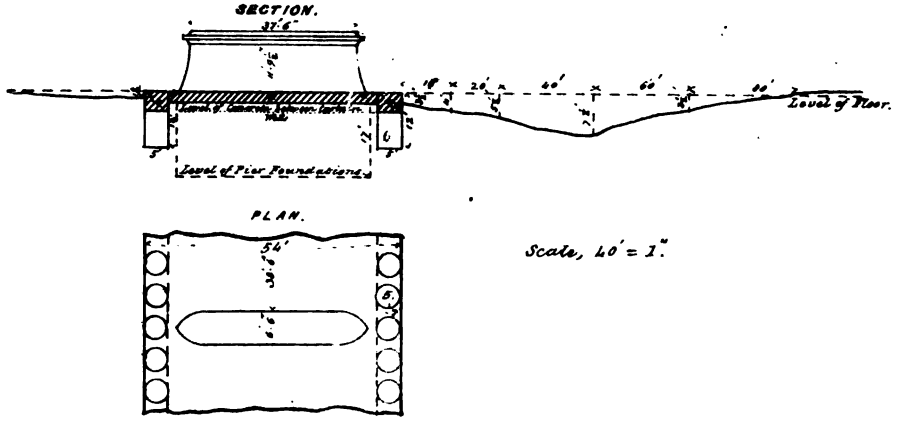
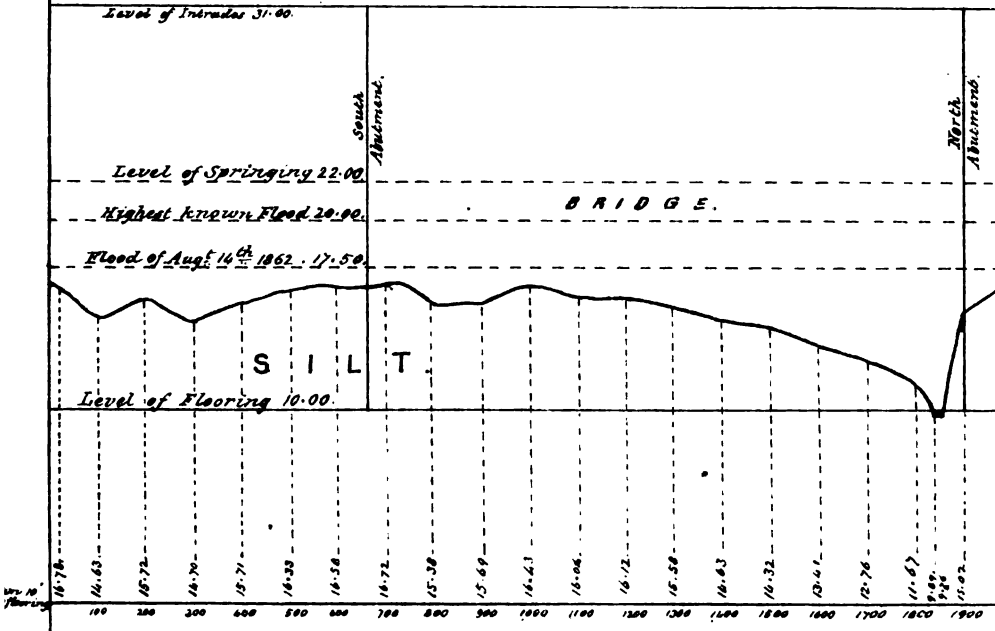
BRIDGE FOUNDATIONS IN SANDY RIVERS.

MARKUNDA BRIDGE.

Sketch, shewing Scour produced by a Flood of 7.5 feet August 14th, 1865.—



Cross Section of Channel taken 500 feet above Bridge, Feb. 26th 1866.



Scales
Vertical 10' = 1 inch.
Horizontal 400' = 1"

LITHO: T.C. PRESS

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could cut a passage for itself through the silt. If a slight heading up, probably not exceeding 3 inches of a 4-foot flood produced such unpleasant effects, what might not be expected from a 10-foot flood, with a fall, for a short time, of 2 feet through the bridge?

In the rains of 1865, the highest flood was about 7 feet on the flooring, and the effects left on its subsidence are shown in the annexed section. It will be seen that there was a scour of 1½ feet on the *upper* side of the flooring, and a hole scooped out on the lower side, 3½ feet deep at the edge of the floor, and 7 feet deep at a distance of 40 feet from the edge. This hole was gradually silted up as the water went down; it was measured when there were 3 feet of water on the floor; probably in the height of the flood the hole was much deeper. The scour was no doubt increased by the obstruction of the masonry supports for the centres, of which there were five in each arch, 3 feet thick and 4 feet high (less than the average depth of silt). But the obstruction of these was as nothing compared to that of the silt banks, which must be looked on as a normal feature, for though swept away more or less in the height of each flood, they are always reformed as the waters go down, and ready to dam up the first rush of the next flood.

It appeared to me, that had the foundations of the Markunda bridge been only 6 feet deep, this flood would have settled the question by carrying away the whole structure, and it became a matter of some interest to investigate the Madras data, which had made so much impression on the Government of India. About this time Major Crofton's Report on the Ganges Canal reached me, and I proceed to give some extracts bearing upon the point at issue. It is hardly necessary to remind readers that the slope of the Ganges canal, in the sandy parts, is only 15 inches per mile, that the depth is only 7 feet, the channel uniform and straight, free from drift, sand hills, or silt banks, and with a stream regular and constant, instead of a succession of *dèbacles*. Here is what Major Crofton says as to the state of the bridges:—

"Holes have been eroded in the bed below the Jowalapoor bridge, and all the falls, to the depths shown in the section. In one instance, at the upper Bahadoorabad Fall, the erosion extends considerably below the bottom level of the foundations. No injury, however, has resulted from this to any of the masonry works, *the talus of boulders and cribwork*, originally attached to each on the down-stream side, having transferred

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the excessive action of the current to a sufficient distance from the works themselves." Para. 4.

Again: "Very deep holes have been formed, as the longitudinal section will show, below all the masonry works in the sandy tracts; in some instances as at the Hafiznuggur falls and the Bailra bridge, extending several feet lower than the bottom of the foundations, but in no case has this affected the stability of the masonry works; *the talus of boulders or kunkur has everywhere proved its efficiency as a means of protection.*" Para. 13.

It is abundantly clear from Major Crofton's Report, that had the bridges on the Ganges Canal been protected by curtains only 6 feet deep (the foundations being of no greater depth) *without any talus*, many of them must have fallen in long ago. It is true that the velocity through these bridges is somewhat higher than that due to the original slope of the bed and the obstruction of the piers, alone, because the general erosion of the channel has converted the bridge floorings to some extent into sunk weirs. But the increase of velocity, due to this cause, cannot be great, for Major Crofton's states (para 29)—"that the heading up is very slight in every case; at some bridges it could hardly be detected by the levelling instrument." And whatever it may be, we have the same evil to contend against at the Markunda bridge, where the flooring is already about 6 inches above the level of the bed above and below bridge; an evil which will increase as the erosion of the channel goes on, until the slope of the bed has accomodated itself to the new regime of the river.

If then, as experience shows, very shallow foundations without a talus are unsafe in a stream with all the advantages of the Ganges Canal, they cannot be safe in a torrent like the Markunda, or those in Madras, with slopes of 3 or 4 feet in a mile. It is now time to examine the deductions drawn by Colonel Baird Smith from the works in Madras, which have evidently all along influenced the Government of India in prescribing the the mode of dealing with the Markunda. These deductions, quoted by Colonel Baker in the letter above referred to, will be found at pages 43, 44, of Colonel Smith's "Report on Irrigation in the Madras Provinces." I beg the reader's particular attention to the parts which I have italicised.

"3*rd*. That in rivers with beds of pure sand, and having slopes of 3½

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feet per mile, such dams* may be constructed and maintained at a moderate expense.

"4*th*. That the *elevation of the beds* of the rivers above the dams to the *full height of the crowns* of these works is an inevitable consequence of their construction, and that no arrangements of under-sluices has as yet been effective to prevent this result.

"6*th*. That in pure sand, acted on by the current due to a fall in the river bed of 3½ feet per mile, and exposed further to the action of floods from 12 to 15 feet deep, well foundations in front and rear, of 6 feet in depth, have been proved, by an experience of 15 years, to be safe.

"7*th*. That with a vertical fall in rear of the dam from 5 to 7 feet in height, a thickness of 2 feet of brick masonry and 1 foot of cut stone, with a breadth of from 21 to 24 feet for the apron, have proved sufficient to insure stability, the only further protection required being *a mass of rough loose stones*, about 9 feet in width and 4 in depth. The loose stone apron should at first have a breadth equal to 1½ times, and a depth equal to two-thirds the height of the dam. The action at the tail of the work, *leading to constant additions to the loose stone*, soon deranges these proportions, and they are given only as guides in the first instance.†

"8*th*. That the *main security of the dam* depends upon the efficient construction and careful *maintenance* of the apron."

In the first place, these deductions apply solely to dams or anicuts, and Colonel Baird Smith makes no reference to bridges in this connection. What he does say about the Madras bridges when describing the Gunnarum aqueduct, will be quoted presently. Now the curtain and flooring system is open to two main dangers. First, that of the water finding its way between or under the curtain wells, and either blowing up the flooring or washing out the sand from under it. This is the objection urged by Major Laughton and by Mr. Campbell. Secondly, there is the danger of holes being scooped out by the scour below the bridge, which may extend back below the bottom of the curtain, and cause it to fall in. Of this I have quoted illustrations from the Ganges Canal.

The first danger can hardly occur to an anicut; the action of the dam

* That is, dams (anicuts) similar to these in Tanjore, for distributing the waters of a river, at the head of its delta, among its several branches.—R. G. E.

† Perhaps some Madras officers will kindly state the size and description of stone used for these aprons, and the extent to which they require renewal every year.—R. G. E.

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raises the bed of the river to a level with the crown of the work, so that the water must find its way down 7 + 6 = 13 feet to get under the upper curtain, which is further protected by an up-stream apron. The solid body of the dam itself, and the strong apron of masonry 3 feet thick, are sufficient to protect the work from being blown up or undermined. The danger of scour below is provided against by the talus of loose stones, which has to be continually watched and renewed. This talus Colonel Baird Smith declares in the case of the anicuts, as Major Crofton in the case of the Canal bridges, to be the main security of the work. It is the omission of this essential protection which appears to me to render the design laid down for the Markunda and other large bridges so insecure. The talus or apron alone, however is not sufficient, unless the curtains be made really impervious, so that there is no danger of the flooring being undermined. For this purpose it would be better to use blocks, instead of wells, both up and down-stream, and to fill up the spaces beween the blocks with accurately fitted piles.

I have not been able to find any description of a bridge in Madras, built over a river with a sandy bed on a slope of 3 or 4 feet to the mile, upon shallow foundations, even with the protection of a stone apron. The Gunnarum aqueduct, which is sometimes quoted as an example, is not a case in point. Colonel Baird Smith gives a description of this aqueduct.* He does not mention the slope of the branch of the Godavery river over which the work is constructed; but I gather from his report that the average slope of the high floods of the main river is from 15 inches to 18 inches per mile; also that the general slope of the country longitudinally is about 12 inches per mile. Probably the slope of the bed under the aqueduct does not exceed the latter amount, and it appears from Major Crofton's Report on the Ganges Canal, para. 131, that the stream is a tidal one, the tides rising and falling 3 or 4 feet at the site of the aqueduct—where there is consequently a considerable break-water on the flooring. The aqueduct consists of 49 arches of 40 feet span; the springing line is 11½ feet above the flooring. The piers rest on wells 8 feet deep: the curtain wells up and down-stream are 4 feet deep. Above and below the curtains are aprons of loose stone, the upper one 5 feet, the lower one 16 feet, wide. The depth of these is not given. The soil is described as " sandy."

* (Irrigation in Madras, pages 111, 118.)

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Colonel Baird Smith evidently entertained grave doubts of the wisdom of pushing economy to such an extreme, independently of the objections to the contracted waterway of this aqueduct. He says: "It seems to be possible to secure foundations on the rivers of Southern India, *with their very low slopes*, by means which, with our own experience of the rivers of Northern India, we should be justified in pronouncing utterly inadequate, and with which in fact we should never dream of operating, since *they would inevitably fail on the first serious trial.*" It is evident that Colonel Baird Smith, never intended to apply the results of the Madras *anicuts*, to the case of *bridges* in Upper India, where the conditions are so different.

The conclusions to be drawn from the facts above described were sufficiently obvious. First, that far too much stress had been laid on the success of shallow foundations in Madras, and that the plan had been applied under circumstances and conditions quite different from those of the anicuts which had furnished the idea; Secondly, that the main and most essential element of the Madras system, the talus or apron, had been entirely omitted; Thirdly, that the foundations of the bridge could not in their existing form be relied on, and that some further protection was necessary.

Several remedial measures suggested themselves; the first being to sink the second row of curtain wells opposite the interstices of the first, as originally intended. This was soon given up, for the following reasons:— As the flooring had been put down, the sinking of a second row of wells so close to the edge would inevitably draw out the sand from under it, and thus give rise to the very evil it was desired to remedy. Moreover, it appeared that the greatest scour occurred opposite the ends of the cutwaters or starlings, being caused by the "swirl" or eddy of the water meeting below the piers. The edge of the flooring was so close to the cutwaters, that the additional width of 6 feet aided by another row of wells would give no protection against this action, and it seemed desirable to extend the flooring further down stream. Lastly, it was considered that a curtain wall in such a stream, unprotected by any apron, and exposed to a scour such as had already begun to show itself, could not be safely made less than 20 feet deep. To sink wells 3 or 4 feet deeper than those on which the piers rest, at a distance of only 7 feet clear from the end well of the pier, was not to be thought of.

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Cribwork, filled with brick or slag, would be as expensive as masonry and less efficient.* No boulders were available for a loose apron, and for the above reasons it was recommended that the flooring should be extended 40 feet down-stream, by an apron of concrete 2 feet thick, terminated by a row of blocks 12 × 6 feet, sunk to a depth of 20 feet, with intervals carefully filled up by piling to within 5 feet of the top, which space was to be occupied by a continuous platform of masonry. It was also recommended that the curved wing walls which had been given in the original design but afterwards omitted, should be restored on the up-stream side of the bridge, as there was a considerable tendency to cutting along the face of the abutment on either bank. The cost of the proposed additions was estimated at Rs. 1,03,782.

In a report, dated 31st December, 1865, which accompanied a revised estimate for the bridge, including the protective works described above, I gave the following summary of the question of foundations :—

" If, as appears from the experience of the Ganges canal, very shallow curtains *without a talus* are not safe in a sandy bed with a fall of only 15 inches per mile, and a depth of 7 to 8 feet, *à fortiori*, they cannot be safe in a torrent like the Markunda, or those in Madras, with slopes of 3 to 4 feet in the mile, and floods of 10 to 15 feet in depth. If, indeed, the curtain be protected by an apron of boulders or cribwork, carefully watched and continually repaired, as seems to be the practice in Madras, the system would, no doubt, be safe; and in situations where suitable materials can be obtained cheaply; it might be more economical than the alternative of very deep wells with no flooring at all. But the Markunda Bridge, as observed by the Government of India, is neither one thing nor the other. *Without* a talus (which owing to the scarcity of wood and stone would be nearly, or quite, as expensive as the deep curtain wall now proposed) the bridge cannot, in the face of the facts above quoted, be considered safe; *with* either of these additions it will have cost more than if built on wells 40 feet deep without a flooring, as originally proposed by Mr. Campbell."

No decision has been come to at present upon the measures to be

* I doubt it. I think the loose brick, which is free to fall down and fill up the sand as it is undermined or sucked away, would be far preferable to the solid masonry flooring proposed, and which would certainly crack when undermined from irregular settlement. The brick slag should be in large masses to prevent its being swept away, and a rough timber grating over it might perhaps be advisable for the same purpose.—[ED.]

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adopted; but I hope at a future time to complete this paper by giving the subsequent proceedings in the case, and the results of the remedies which may be applied to the evils that have shown themselves.

Postscript.—Since the greater part of this paper was written, several pieces of the flooring have fallen in, having been undermined by the sand being washed out between the curtain wells. In one spot at least there appears to have been a regular stream flowing through *under* the flooring, from the upper to the lower side of the bridge. The anticipations expressed by Major Laughton in 1856, by Mr. Campbell in 1860, and by myself in 1865, have been fulfilled.

R. G. E.

Memorandum by the Superintending Engineer.

I have not been long enough in this circle of Superintendence to have acquired much personal knowledge of the conditions of the Markunda river, and the experience of one comparatively scanty rainy season cannot be considered as full data.

But however applicable the system of shallow foundations, with protective pavements and curtains, may have proved in the Madras Presidency, there has not been as yet, that I have seen, any record to show that General Cotton has considered this system to be applicable to bridges over rivers of great slope, in very light or sandy soils; and which, in Northern India, are further subject to sudden and violent floods, causing a velocity much in excess of the velocity as calculated from the slopes of the beds.

It is further clear that the liability to cutting under the bays of a bridge is much greater than in the case of dams and weirs, so that the latter cannot be accepted as a guide to the former.

The system of shallow foundations was introduced into the N. W. Provinces about sixteen years ago; and I was, I believe, one of the first to take up the idea in its experimental application to bridges. These experiments were limited to drain bridges of two or three arches, each under 20 feet span, including some long and low viaducts with arches of 10 or 15 feet span, with the prescribed protective pavements and cur-

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tains, and always with the addition of enrockments or tail pieces below bridge, in cases of much velocity. The conclusion to which these cases have led me is that the system of shallow foundations, with its adjuncts, will generally be sufficient for drain bridges in moderately firm soil, without much slope, supposing the whole to be under periodical supervision.

But the same experience, combined with later inspections of large bridges in sand or sandy soil within the N. W. Provinces and the Punjab, has convinced me that there must generally be true economy in such cases, by sinking the foundations proper, *i. e.*, those under the piers, abutments, and even wing walls, as far as they can be driven without extraordinary exertions, and under no other limit, short of 40 feet, which will in almost all cases be deep enough to be beyond the action of the water, with sufficient lateral pressure on the wells or blocks, to support the bridge. The value of this support will of course be greater in proportion to the advisability of dividing the total weight over many lines of support, but in this consideration the question of economy, as well as of waterway, will enter largely.

Under any circumstances, the foundations should evidently go deeper than the possible action of the water.

Pavements, with curtains of more or less depth, are always useful in cases of considerable velocity to equalize the action of the stream through the bays of a bridge, and I have always found enrockments or tailpieces to be much more valuable than seems to be generally supposed. They prevent serious injury during the floods of one season, and if partially displaced, they serve as a warning to adopt further measures.

But curtain walls cannot be used in all situations. Such curtains imply a stoppage of the water below the river bed, and it follows that any undercurrent filtering through sand, must be forced either above or below the curtain. The former would be inconvenient as raising the head of water, and the latter would be fatal both to pavements and curtains.

Against the system of shallow foundations, with their adjuncts, in sandy soil, is the clear fact that the least derangement, causing a movement in such soil, must upset all previous calculations, and there is no saying when sand, once in movement, may stop.

A large bridge is I believe the last kind of structure to be considered in the most economical point of view, so far as the foundations under piers and abutments are concerned. Further, the cost of pavements, curtains,

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and tail pieces, with their after repairs, will I think seldom leave much in favor of shallow foundations, as compared with deep foundations in the first instance, which do not require all these adjuncts.

The case of the large Markunda bridge may be considered as a bold experiment, made with the special object of placing beyond doubt if possible, the economy of shallow foundations in the Punjab; but present appearances are not in favor of the theory, although the sinking of some of the pavements is doubtless partly due to the mode of construction, as carried out from motives of economy. There have also been strong symptoms of a tendency to extensive cutting below bridge, which has necessitated the proposed addition of a broad tail piece of masonry, failing the presence of stone within any reasonable distance, and this cutting is of course quite independent of the mode in which the pavements and curtains have been built, while it would always threaten shallow curtains, however well built, if allowed to go on. The foundations proper have not yet been affected, and the expense to be now incurred for further protective measures, may be fairly calculated against the expenditure saved in the first instance, by avoiding deep foundations, and in the economical construction of the pavements and curtains.

It may be remarked of the system of shallow foundations that they cannot be expected to last long, without constant or periodical repairs to the protective works.* Such protective works connected with works of irrigation in the Madras Presidency probably *pay* while they last, which is doubtless a sound calculation (so far as the Public Works Department is concerned), when capital is not immediately available for extensive works on a more permanent basis: but it seems equally evident that works of a permanent nature would *pay better*, supposing capital to be available. Expenditure on original works is generally a more prominent matter, and more apt to catch general attention than a succession of expenditure on repairs, and we have to consider that in many parts of Northern India, the means of periodical repairs are comparatively expensive from the scarcity of wood and stone.

The quotations made by the Executive Engineer from the opinions given by several Engineer Officers, and from the orders issued by Govern-

* And probably, constant attention to the state of the river bed, so that accumulations of silt formed during the rains, and causing an irregular current through the bays, should be regularly cleared away in the cold weather.—[ED.]

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ment on the subject of the Markunda bridge, all lead to the conclusion that a question of admitted difficulty, has been put to the test in a form which must go far to prove the advisability or otherwise of shallow foundations (with their adjuncts) in Northern India. There seems to be nothing in any of the opinions or orders given, to be taken as a positive expression of opinion on the subject, and nothing can be better under all circumstances than the tentative process now in course.

It is further due to Colonel Yule's suggestions, to state that his suggestions have not been fully carried out, and that the substitution of inferior and more economical materials in the pavements, &c.,* appear to have been altogether due to the Executive Engineer of the time being. So far, the test, as yet, has only been a partial one.

J. D. C.

* With the omission of a row of wells.

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No. CXIX.

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

(4TH ARTICLE.)

Compiled from the Annual Reports of MAJOR-GENERAL SIR ANDREW WAUGH, R.E., F.R.S., *late Surveyor General of India.* BY H. DUHAN, ESQ., *Personal Assistant to Surveyor General.*

THE next party to be reported on is the *Madras Topographical Survey* party, under Captain Saxton. Although the tract inhabited by the Gonds and other aboriginal tribes, extending from near the Coromandel coast to the Nagpore territories, is not of much value to the revenues of the British Government, and is peculiarly difficult to survey on account of the physical features of the country, as well as its insalubrious character, still a general survey of the whole tract on a moderate scale appeared an important requisite for political and military purposes, and the general objects of Government; accordingly arrangements were made for a scientific survey of Ungool and the surrounding country, work being commenced at the extremity of the South Parasnath Series near Balasore, which enabled Captain Saxton to commence with data furnished by the G. T. Survey, thereby securing accuracy and saving much time and trouble in measuring base lines and determining a point of departure.

Captain Saxton reported that the whole country was jungle, but the ranges appeared favorable for triangulation, which the party proceeded to lay out in advance. A little after the middle of December,

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sickness commenced; and shortly afterwards, increased to an alarming extent. Captain Saxton, and two of his assistants, were compelled to proceed to Cuttack for medical aid, and the whole party was in fact disorganized; the season's operations proving thus nearly a failure.

Notwithstanding the anxiety which these untoward circumstances occasioned, the Surveyor General felt reluctant to declare the undertaking impracticable. The unhealthiness of the climate in all December being clearly demonstrated, orders were issued that the party should not reach their ground before 1st January. On the other hand, the climate becomes dangerous by the middle of March. The season being thus limited, it was a great object to strengthen the party as much as possible, which having been done, the results of the next two seasons were more satisfactory. The hill tract under survey was reported as being covered with dense and unwholesome forests, hardly animated at long and distant intervals by a sparse population of aboriginal tribes in the lowest stage of barbarism. The area surveyed was 2,515 square miles, of which 565 were on the one inch, the remainder on the half-inch scale.

In 1849, immediately after the conclusion of the Punjab war, a survey of the neighbourhood of Peshawur was commenced at the desire of the Military authorities by Lieuts. Garnett and Walker, Engineers, which was gradually extended so as to include a *Military Survey of the Northern Frontier Trans-Indus*, the operations being placed under the control of the Surveyor General. 400 square miles were completed by June 1849, when Lieut. Garnett was sent to Kohat, and the work was continued by Lieut. Walker* alone. That Officer adopted a scale of an inch to the mile, except in the vicinity of the city of Peshawur, where the work was taken upon the 2 inch scale. The instrumental equipment was unfortunately of a small kind, as instruments of the highest power could not have been employed or carried in such a disturbed country.

Operations had been commenced by measuring a base line of 2¼ miles in length, and triangulating therefrom. The sides of the triangles varied in length from 4 to 16 miles, their general average being 6 miles. By December 1849, Lieut. Walker had completed the survey of the

* Now Lieut.-Col. Walker, R.E., Superintendent G. T. Survey, and Officiating Surveyor General.

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ground south of the Caubul river, and east of the city as far as Naoshera. He was then directed to accompany the field force proceeding to Eusoofzai, during which time the survey was of necessity discontinued.

Immediately after the close of the military operations, a survey was ordered of the valley of Loondkhwar in Eusoofzai. Having no time to carry up the triangulation from Naoshera, a new base was measured, and a survey made of 150 square miles, on the scale of 2 inches to the mile. This being effected, Lieut. Walker triangulated backwards to his former network, and found a difference of 2 yards per mile in the common side of junction. This is a degree of error to which minor triangulation depending on bases measured with common chains at different seasons, carried on with small theodolites reading to minutes, and with indifferently marked signals, seems to be fully liable, and which can only be avoided by the rigorous precautions of the G. T. Survey system. About the middle of May, Lieut. Walker returned to cantonments for the recess, during which a map was made of all the country that had been surveyed, and a copy forwarded to the Board of Administration at Lahore.

Ill-health prevented his returning into the district before the end of November, about which time he recommenced operations from the vicinity of his base line in Loondkhwar, proceeding east to the Indus, thence south to Attock and finally west, until a junction was again formed with the former triangulation terminating at Naoshera. To test the accuracy of these operations he measured a third base near the banks of the Indus, and found a discrepancy of a yard per mile. The work was improved by the grant of additional establishment, enabling the stations to be marked by pillars, but the telescopic power of the theodolite was so feeble, that opaque signals were seen with great difficulty, and the accuracy attainable was thereby greatly limited.

The area surveyed up to the end of season 1850-51 was reckoned about 3,100 square miles, of which nearly 2,000 belong to the British Government, and the remaining 1,100 to independent Pathans. This last portion, though hostile, was surveyed with nearly as much accuracy as the former, and on the same scale. The cost was about Rs. 3¼ per square mile. By September 1851, a map was completed of the whole valley of Peshawur, including Eusoofzai, and as much as Lieut. Walker

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could get access to, or see distinctly, to the north and west beyond the frontier.

His adventures while surveying among hostile tribes were of a most interesting description, and often attended with great risk. He had frequently to obtain access to his stations, by causing diversions to draw off attention for a limited time, during which he had to take his observations and then ride hard for life. By tact and management, as well as cultivating friendly relations with the Chiefs, he succeeded in conducting his work without collisions, and with only a single accident, on which occasion his native groom was killed.

Having been supplied with more powerful instruments, the survey was continued during the following season, being first connected by a series of triangles with the Base at Attock, so as to form part of the G. T. Survey. Lieutenant Walker's Khattak Hill Series orginates from the side, Attok to Pir Subak, of the G. T. Survey, and was skilfully conducted to Kohat. Owing to the dangerous character of the Afridi tribes, his scope of selection was limited. For the same reason the connection of Kohat and Peshawur, though only 30 miles apart, was of necessity dependent on a series of triangles nearly 150 miles in circuit. These deviations from a direct course were unavoidable, and are mentioned only as illustrating the peculiar difficulties of the survey.

During the season 1852-53, Lieut. Walker completed the survey of the whole highland frontier Trans-Indus, embracing the Southern Khattaks and Bunnoo, besides extending a reconnoissance into the plains of the Deraját, as far as Dera Ishmael Khan. In the progress of his operations, he took many observations for fixing the chief visible points of the ranges beyond our boundary. Fourteen peaks were thus determined, extending over a distance of 50 miles along the summit of Safed Koh, or the White Mountains, which constitute the watershed between the Cabool and Koorum rivers. Thus, and with the assistance of native information, he made a tolerable map of the country beyond our boundary, as far west as 69½ of longitude.

The total area of British territory thus brought under survey, exceeds 6,000 square miles; and the survey has been of the highest utility in the subsequent numerous military operations against the frontier tribes.

In the season of 1853-54, the Surveyor General measured the Base

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Line near Attok in the plains of Chuch. Subsequently, the Base Line apparatus was carefully transported to Karachi, where in the season following, the Karachi Base Line was measured. These two Base Lines complete the linear verifications required for the great quadrilateral figure of Sironj, Dehra, Attok and Karachi. The results of the verification of the important series of triangles terminated by these bases are given below; and considering the extent of the triangulation they must be considered satisfactory.

Error of North-west Himalaya Series at Chuch Base line, (the value by triangulation being in excess,) 1·262 feet or 0·30 inches per mile.

Error of Great Longitudinal Series at the Karachi Base line, (the value by triangulation being in defect,) 1·165 feet or 0·17 inches per mile.

During the previous year, Major (then Lieut.) Tennant, R.E., had been directed to build an observatory on a favorable site selected for the purpose near Karachi, in order to verify by celestial observations the value of Latitude and Azimuth brought down from Sironj by the Great Longitudinal Series. One of the great Astronomical Circles employed on the Great Arc was used for this purpose. The results were as follows:—

		Latitude.		
At Karachi observatory,	by celestial observation,	94°	49′	49″·273
„	by Great Longitudinal Series,	94	49	50″·155
	Discrepancy,	0	0	0″·882
		Azimuth.		
At Karachi observatory,	by celestial observation,	179°	59′	57″·425
„	by Great Longitudinal Series,	179	59	57″·737
	Discrepancy,	0	0	0″·312

This officer also successfully carried out a series of Tide Observations with a self-registering gauge, for the purpose of determining the datum at Karachi for the survey heights.

During 1858, arrangements were made for carrying up a special series of *Levelling Operations* from the tide gauge at Karachi to the Chuch Base, for the purpose of determining accurately the height above the sea level of stations in the interior, and furnishing a precise datum for the mountain operations. Hitherto the heights determined

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by the G. T. Survey of India have been deduced entirely by means of reciprocal vertical angles, except in the case of short levelled lines necessary to connect the tide gauges with the nearest stations of the triangulation. Since the improvements introduced in the process of Trigonometrical levelling, the results have proved highly satisfactory, especially in hilly tracts, where, from the nature of the circumstances, spirit levelling is inadmissible, and the Trigonometrical process by reciprocal verticals can be practised under great advantages. In the plains, however, the case is reversed, and on account of the uncertainties of terrestrial refraction in rays grazing so near the surface, great anxiety was felt lest error should accumulate in such long lines of operations, as the survey had to deal with in the plains of Northern Hindostan. The very accurate results obtained by the Trigonometrical levelling have already been remarked, (see page 104,) but they nevertheless appeared to the Surveyor General not sufficiently in keeping with the wonderful precision attainable in all the other results of the survey. Much depends on an accurate determination of the height of the base lines, in regard to their reduction to the sea level, which affects the lengths of the arcs and all the linear distances of the Survey. It was also a matter of great interest to bring up an accurate datum from the sea to the Himalayas, in connection with the determination of the heights of those stupendous peaks. It was further a matter of importance to furnish an accurate datum to the Canal Departments of Sind, Punjab and the N. W. Provinces; and to connect their levelling results, and those of the Railway Department, with our own. For all these reasons, it was determined to carry a line of levels up the valley of the Indus with the greatest precision attainable, and with all due attention to the extraordinary refinements usually practised in Trigonometrical operations, though not hitherto attempted in ordinary levelling. The great distance to be levelled, and absence of the means of verification at the termination, rendered unusual precautions indispensable.

The first part of the Indus Series crosses a hilly tract, and a similar highland region occurs before the triangulation terminates at the Chuch Base, a distance of 960 miles. With these exceptions, for the greater part of its course the series traverses, by the aid of towers, a flat alluvial plain. The party under Major Walker was equipped with

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THE GREAT TRIGONOMETRICAL SURVEY.

Towers erected for the principal Triangulation in the Plains.

Fig. 2.
Transverse Section.

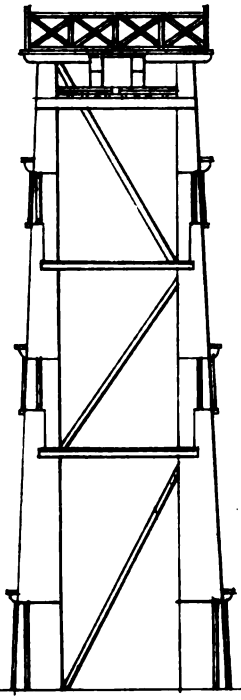


Fig. 1.
Elevation.

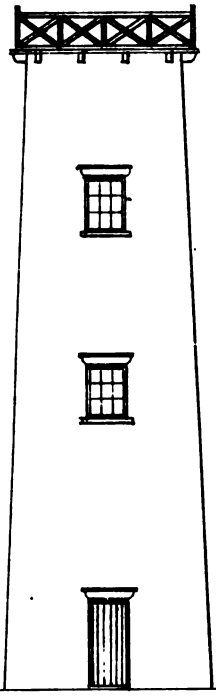


Fig. 3.
Ground Plan.

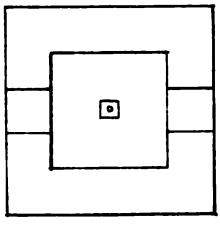


Fig. 4.
Plan of 1st. Story.

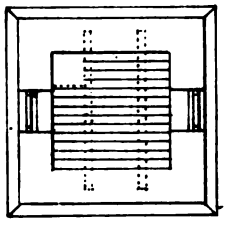
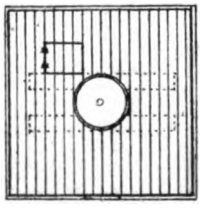


Fig. 5.
Plan of Platform.



Scale 15 feet = 1 inch.

1' 5' 10' 15' 20' 25' 30' 35' feet.

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three first-class standard levels by Troughton and Simms, transferred for this purpose by the Punjab Canal Department. These had powers averaging 42, and a focal length of 21 inches. Graduated scales were attached, so that the level errors could be recorded and corrected for, in the same way as in Astronomical observations. It is humanly speaking impossible to level an instrument practically without some residual errors, however small, but it is practicable to note the errors and compute the corrections due to them, a process by which accumulation of small errors is prevented. The staves were made for the special purpose in the Mathematical Instrument Department, graduated on both faces in a peculiar manner, and with every precaution as to conformity with the unit of measure of the Indian Survey. For the subsequent verification of the unit, a standard bar was supplied as a provision against accident or change in the staves.

As a precaution against the intrusion of gross errors and to lessen the anxiety which a single leveller must experience if he works alone for months, without knowing whether his results are accurate or not, it was determined that three observers should level along the same pins one after the other, using each his own instrument and staves. Thus, any error could at once be detected and rectified on the spot, and the work was thus subjected to check at each step of its progress.

The operations commenced at Sojra tower, and the levelling was carried upwards in a continuous rise. After proceeding some distance a personal error was discovered of a very minute but constant character, whereby the results of the three observers diverged from each other. Though the differences were extremely small, their constant character gave reason for anxiety in regard to their accumulating tendency on a long line of 960 miles. This led to a long discussion, which ended in the adoption of an alternating system of observation, whereby the benefits of a circuit system were obtained, and many sources of instrumental error counterbalanced. By these means, the differences between observers were much reduced, and in some cases counteracted. The work beginning at early morning at the lowest temperature and maximum amount of aqueous vapour, it was evident that as the temperature rose the air became drier, and the refraction constantly diminished. Though the difference taking place in the interval between a back and forward sight, was extremely small, and its effect

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almost insensible on the third place of decimals of a foot, still the tendency being constant, its accumulative effect might be dreaded on so long a line. For these reasons the staves were observed, and the observations repeated in an alternate manner at each station, as also at alternate stations. Similar precautions against the accumulation of minute quantities were taken in the manipulation of the instruments. In order also to introduce the highest degree of refinement the work was susceptible of, new levels, freely mounted and supported at the two points of least flexure, and covered with glass cases, as a protection from currents of air, were prepared in the Mathematical Instrument Workshops.

In the course of these levelling operations, numerous bench-marks were buried at important places, seven canal and railway bench-marks were connected and nearly 200 mile-stones marked. The connection with the Canal and Railway affords a check by circuit. For example, Major Walker's levels from Shikarpore to Kotree *viâ* Larkhana and Schwan, with the Canal levels *viâ* Sakkar and Hydrabad, close with a discrepancy of only 0·09 foot in 560 miles.

The result obtained from this series of levelling operations is most satisfactory, and indeed, may be pronounced a triumphant feat; as will be seen from the following statement, viz:—

1.	From Karachi sea level to Chuch Base (Spirit levelling), ..	960	miles.
2.	N. West Himalaya Series, (Chuch to Banog,) Trigonometrical mountain levelling, ...	412·8	„
3.	Great Arc Series, from Banog to Sironj, ...	445·0	„
4.	Great Longitudinal Series, Sironj to Karachi sea level, ...	678·4	„
	Total length of circuit,	2496·2	„

This circuit of levelling, chiefly Trigonometrical, and embracing 210 miles of Trigonometrical levelling over plains, closes with a discrepancy of 0·753 of a foot, giving a rate of only $\frac{1}{10000}$ of a foot per mile.

On the Great Indus Series there were two independent levelling operations, viz.: —1st, The Trigonometrical levelling along the series which is 710 miles in length, of which 384 are unfavorable plain country; and, 2nd, Spirit levelling over a circuitous route of 960 miles. The comparisons between the two results at the points of connection along

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the series are highly satisfactory, and the ultimate results most gratifying, as will be seen from the following statement:—

	Feet.
Height of west end Chuch Base, by Spirit levelling, brought up from the sea level at Karachi, ...	1014·603
Height of same point brought up by Trigonometrical levelling, from same datum, ...	1012·30
Difference between Spirit and Trigonometrical levelling,	2·303

This gives a rate of error on 700 miles of ·003 of a foot per mile, which is wonderfully accurate for Trigonometrical levelling, especially over a tract of 384 miles of unfavorable country.

The next series to be reported on is the *Kashmir Series*. After the completion of the Karachi Base, Captain Montgomerie R.E., was deputed on this duty, and commenced Trigonometrical operations on the Kashmir meridian. The first season's triangulation having been laid out across two ridges of the snowy mountains, and advanced into the heart of Kashmir, the Surveyor General proceeded to organize arrangements for the Topographical Survey, which was to be based on this triangulation. On account of the small establishment at disposal, the difficulty of obtaining Uncovenanted Assistants, owing to the competition of other departments of the State, the length of time consumed in training new hands, and the difficulty of retaining them when trained, application was made for three or four young Officers of the Quarter-Master General's Department, to survey during the summer. Three officers, viz., Captains P. Lumsden, C. C. Johnson, and G. Allgood were accordingly temporarily transferred. Lieut. Elliott Brownlow of Engineers, with two assistants from other parties, were also allotted to the mountain survey. By this means the Trigonometrical establishment was strengthened sufficiently to advance the Great Series towards Thibet, and at the same time cover the area to be surveyed with points of reference for the topographical operations.

The system of survey adopted was that described in the Topographical instructions for the Department. The advantage of this system in a country like India, especially in the hilly and mountainous tracts is, that officers with a moderate previous knowledge of military drawing can readily be trained to fill up the triangles; and the work proceeds rapidly, producing a complete and valuable map, with the topographical features accurately delineated at small expense.

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The three Assistants Quarter-Master General being wholly untrained to the rigorous system of surveying required, had first to be instructed; but were after a moderate probation able to proceed independently, and by the end of the season had accomplished a fair share of excellent work. For the ensuing season of 1857, it was fully expected that these three officers would have been again available. Unfortunately the exigencies of the service did not admit of this, and their previous season's training was thus lost to the survey.

The arrangements made for the prosecution of the Topographical survey having thus broken down, the whole business of training and instruction had to be recommenced *de novo*. Three other officers with the requisite qualifications were selected, viz., Captain H. H. Godwin-Austen, H. M.'s 24th Foot, Lieut. A. B. Melville, 67th N. I., and Ensign W. G. Murray, 24th N. I. These officers speedily learned their duty, and did excellent service. The strength of the Kashmir party was also increased by Lieut. Basevi of Engineers, and Assistants from other parties being transferred for the summer season.

Neither the physical character of the country, nor the constant task of training new hands formed the chief difficulty of the survey conducted in a foreign territory, and which at no time could be expected to be agreeable to the Ruler, his officials, and people. To them the influx of a considerable body of surveyors, spread over the country, however orderly and well conducted, must bear the aspect of intrusion. Captain Montgomerie had some difficulty in maintaining amicable relations with the Court, and his difficulties were enhanced by the Military Rebellion of 1857, during the whole of which excited period the party continued its peaceful and useful labors without cessation, and with only one serious interruption.

The character of a Trigonometrical survey demands that the stations shall be fixed on the highest summits, or on points commanding extensive views, and it is requisite that an adequate number of good observations shall be taken, which usually occupies several days. To accomplish this task, not only the observers, but the signal men (natives), must encamp at or near the stations. The heights of some of the peaks ascended on the Punjab range were Moolee station, 14,952 feet; and Ahertatopa station, 13,042 feet; and to the north of Kashmir, Haramook, 16,015 feet. Among the highest elevations visited in Thibet

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were the principal stations of Shimshak and Shunika, 18,417 and 18,224 feet, respectively. The difficulty of obtaining supplies and firewood at such elevations may be imagined, yet they were every day occurrences. Out of sixteen principal stations in Thibet, fourteen exceeded 15,000 feet in height.

Although the splendid climate of Kashmir, added to the special interest attaching to the country and the unexplored tracts adjoining, made the survey deservedly a great attraction, still the exposure of surveying in such a country is very trying to the constitution, and many persons suffered greatly. The lower valleys are very hot, and the solar radiation on the hill sides is very powerful. The labor of climbing to great elevations has often been noticed by explorers; the surveyor, however, arriving heated by physical exertion at great elevations, has to stand on ridges or peaks, exposed to strong cold winds, while he is observing angles or sketching the ground.

The whole mountain tract south of Kashmir proper was completely triangulated and topographically surveyed. In 1859, the triangulation was satisfactorily advanced in Thibet, but the Topographical operations made slower progress than usual, owing to the smallness of the establishment the Surveyor General was able to devote to that work. The work effected may be briefly summarized as follows:—

1st. Area triangulated from commencement of survey to 1859, about 50,000 square miles, (nearly equal to the area of England,) five years.

2nd. Area topographically surveyed in four years, about 23,000 square miles.

3rd. Cost per square mile, Rs. 4-5-2.

These results are highly satisfactory in quantity, quality, and cost.

The Coast Series is a most important work, as it connects the metropolis of India with the Madras Observatory, which is the origin in Longitude of the Survey of India. This operation also defines the coast. Unfortunately, however, the triangulation traverses a country presenting formidable difficulties, among which, the baneful climate may be reckoned the worst. The work was commenced at the Calcutta Base by the late Captain Thorold Hill, who was succeeded by Mr. Clarkson and Mr. Peyton. The obstructions presented by the climate and other difficulties were so great that the progress had been

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slow, and the cost correspondingly high. The parties had been annually decimated by sickness and driven thereby from the field. But the work was nevertheless, with singular constancy and perseverance, gallantly resumed, season by season, until by slow degrees it nearly reached Cuttack.

The Rahoon Meridional Series commenced in 1852, was necessarily suspended during the two following seasons, owing to the party being employed at the measurement of the two Base Lines. Work was shortly after resumed, and the series progressed satisfactorily. The party after the conclusion of the season's work in 1857, on returning to recess quarters, passed through Delhi and Meerut only a few days before the out-break of the mutiny, thus narrowly escaping destruction. In 1857-58, the country south-west of Delhi, through which the series passed, was so disturbed that operations could not with any regard to safety be resumed. Next year the country still being unsettled, the party was transferred to the Gurhagurh meridian, under Major Tennant.

The Gurhagurh Series was undertaken to lay down Ferozepore, and furnish fixed points for the incorporation of the Revenue Survey with the general map of the Punjab. The season proved unfavorable, and but little final work was done; but good progress was made in 1859-60 by Mr. Shelverton, who succeeded to the charge of the series, on Major Tennant's appointment to be Astronomer at Madras. Lieut. Herschel of Engineers, was appointed to fill Major Tennant's vacancy.

Mr. Nicholson's health having succumbed to the baneful climate of Assam, Mr. Lane was deputed to succeed him in the charge of the *Assam Series*. He pushed forward the work with great energy, accomplishing an excellent season's progress; but the mutiny having broken out, his party was in some danger from roving bands of mutineers, chiefly of the 34th Native Infantry. In the seasons subsequent to 1857, the progress of this work diminished, owing to the difficult and unhealthy character of the country, and its destructive climate.

The next Trigonometrical operations to be reported on, are those conducted in the Bombay Presidency. *The Bombay Trigonometrical Party*, under Captain D. G. Nasmyth, R.E., had been employed south of the Great Longitudinal Series in triangulating Goojerat, Katyawar, and Cutch, and connecting the operations with Sind. Crossing the

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Runn of Cutch and the little desert, the nature of the country presented obstacles of the most formidable character, as well in regard to provisions, water and travelling requisites, as in finding suitable sites for towers, and the materials for their construction. The observations also from atmospheric vapour and mirage, were rendered peculiarly difficult and harrassing. The whole tract of country embraced by Katyawar and Cutch was fully triangulated and prepared for Topographical Survey. The numerous series into which this triangulation is divided, close most satisfactorily, showing extreme accuracy of observation, beyond what could have been expected from an 18-inch and 12-inch instrument.

Captain Nasmyth proceeded to England on furlough and was succeeded by Lieut. Haig, R.E., who was employed in the ensuing season in completing the Gogo Series, and forming a connection between the Aboo and Singi Meridional Series.

It is now necessary to summarize the proceedings of the various *Topographical* parties. Of these, the Kashmir Series has already been reported on in connection with the Trigonometrical operations under Captain Montgomerie.

Captain D. G. Robinson's survey of Jhelam and Rawul Pindee is second to none in importance, or in the excellence of its results, and the interest attaching to the locality. This great work was commenced by Captain Robinson at the close of the year 1851, and the field work was brought to a successful conclusion early in 1859. The area comprised in this survey amounts to 10,554 square miles, so that the rate of progress has been 1,319 square miles per season. The progress would have been more rapid but for several retarding causes. The cost of the eight field seasons amounts to Rs. 1,93,465-15-10, which, divided by the area, gives Rs. 18-15-2 per square mile, for the rate of the field-work.

The scene of this survey is of great interest and importance in a classical, military, geological and engineering point of view. The locality is rendered memorable as the scene of Alexander the Great's exploits, and as embracing the line of operations by which India has been invaded from the time of Alexander to that of Nadir Shah and Ahmud Shah Abdalli. It abounds in strong positions, and an elaborate and accurate map of this part of the country is therefore of great im-

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portance in a strategic point of view. To the geologist it is of importance as containing the saliferous strata of the Salt range, and various formations of great interest and curiosity. In an engineering point of view, the utility of an accurate survey is manifest, and Captain Robinson's results have proved useful in facilitating the operations of the Great Road.

After the measurement of the Chuch Base, Mr. Mulheran an experienced surveyor of the department, assisted by Mr. Johnson, was deputed to finish a small portion of the great snowy range, lying between the heads of the Baspa and Ganges rivers, including the Nela Pass, which had not been travelled by Europeans or natives for many years, owing to the danger attending the crossing of the lofty and difficult part of the range. The Nela station is 19,086 feet high, and on account of its southern aspect and consequently greater depth of snow, the ascent is a more difficult achievement than an ascent to a similar altitude on the north side of the Himalaya. Mr. Johnson surveyed all the difficult ground at the head of the Baspa and Nela pass, as well as from Nilang to the Jala Kanta pass; while Mr. Mulheran finished the difficult ground at the head of the Charang, Nisang and Rishi Dogri, in Bissahir, east of the Sutlej, and continuous with Chinese Tartary. After this feat, the party was transferred under Captain Montgomerie to Kashmir, and Mr. Mulheran proceeded to organize the *Hydrabad Topographical Survey*. Mr. Mulheran's superintendence of this Survey proved successful, and justifies the expectation that the remaining portion of this survey, which embraces no less than 95,000 square miles of country, or an area larger than Great Britain will be finished in a moderate time.

In the year 1858, the Deputy Surveyor General applied for Trigonometrical points on which to base the Nagpore Revenue Survey. The Great Trigonometrical Survey not having been extended over that part of the country, Mr. Mulheran was deputed to carry a branch Series from the Great Arc to Nagpore.

(To be continued.)

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THE GANGES CANAL COMMITTEE.*

In a former number of these papers, an attempt was made to give a brief and impartial account of the Ganges Canal controversy. As this has since passed through several new phases, it will probably be interesting to our readers to show what has since been done, and what new data of professional interest have been elicited.

In January 1864, a Committee of Engineer Officers, composed as under,† and comprising the ablest Irrigation authorities in Upper India, was convened at Agra, and a Memorandum drawn up which set forth briefly as follows:—That it was admitted by every one that the Ganges Canal was originally designed with too great a declivity of bed, and that in consequence of this mistake, considerable erosion of the earthen channel had taken place, and many of the masonry works were in danger of being undermined and destroyed—That without extensive alterations, the present canal could not safely carry the full supply of water which it had been originally designed to pass, and that the carrying out of such alterations would probably render necessary a temporary closure of the canal to the serious detriment of the irrigation interests of these provinces—That the amount of water which the present channel, if *unaltered*, could safely carry, being inadequate to the wants of the country, the rest of the available supply might *perhaps* be carried by a supplementary channel from Roorkee through another part of the country, and which should rejoin the original channel lower down—That an officer of experience (Captain Crofton, R.E.) should

* Report of the Ganges Canal Committee. Roorkee, 1866.

† Col. Strachey, R.E., Secretary to Government, P. W. D.; Col. Morton, R.E., Chief Engineer, N. W. P.; Col. Turnbull, R.E., Superintendent General of Irrigation, N. W. P.; Capt. Dyas, R.E., Superintendent General of Irrigation, Punjab; and Capt. Crofton, R.E., Superintendent Eastern Jumna Canals.

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be appointed to report on the whole subject, and especially on the two alternative schemes above sketched.

In November of the same year, Captain Crofton submitted his Report, and a perusal of it will amply justify his Chief's encomium of "the energetic and able manner in which he has in so short a time accomplished a most arduous task." This report gives 1st, A complete account of the present state of the canal; 2nd, Recommendations for remodelling the present line so as to enable it to carry the full supply with safety; 3rd, A project for the alternative or supplementary line; 4th, A design for a separate *navigable* line (apart from irrigation); 5th, A comparison of projects and cost; 6th, A reply to Sir Arthur Cotton's objection to the general design of the canal. The general conclusions to be drawn from the whole Report are—That the preferable alternative is to remodel the present line, both on the score of efficiency and economy; and that Sir Arthur Cotton's proposals were altogether impracticable.

The principal measures recommended for remodelling the existing line were briefly as follows:—1. Reduction of the slope of the bed (by the construction of additional falls), and increase to the sectional area of the channel, with an additional opening to the bridges. 2. Alteration of existing Ogee Falls into Vertical Falls with gratings. 3. Raising bridges where the headway is insufficient. Of these measures it is obvious that the first was by far the most important and expensive, and that the third has reference to navigation requirements only. The total estimated cost of these alterations was Rs. 39,19,850, or including compensation for temporary closure and loss of revenue, Rs. 52,68,063, which would finally raise the total cost of the canal to 2½ millions sterling.

Examining this Report somewhat more in detail, the following facts are elicited. As to the present state of the canal: the violent action of the water has chiefly shown itself in scouring large holes below the Bridges and Falls, but the former, protected by the *talus* of boulders and crib-work, are perfectly safe—the latter, where the falling water has of course added greatly to the dangerous action, have not been materially injured, except at one or two works, where inferior masonry had been used—here the floorings were torn up

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and the foundations endangered.* This action was further increased (and the canal banks also much cut away below) by the inward curve given to the water-walls on each bank. In the case of the Bailra Falls, where the material was no better, the water-walls, being curved *outwards*, formed a large basin, in which the velocity of the water shot down the ogee fall is destroyed, and thus a greater depth of back-water secured on the flooring; here the injury done was trifling. The difficulty of executing the necessary repairs to these works has simply been in the fact of the water having to be turned on (when the canal was re-opened) before the masonry had had time to dry. There seems no reason to doubt, that first rate brick masonry is both hard and strong enough to resist the most violent action of the water, when there is no defect in the original design.

From a variety of observations, given in detail, in an interesting Appendix to the Report, the safe maximum velocities for the remodelled channel have been taken as 2·5 feet per second for the worst soil, such as sand hills; at 2·7 feet for sandy soil generally; and at 3 feet per second for the ordinary soil met with (a light clay).

This Report, it may be observed (as well as the Memorandum by the Committee of Engineers in which it was based), was drawn out without any direct reference to Sir Arthur Cotton's views; which are, therefore, only incidentally replied to among the "Concluding Remarks," and to the most important of that Officer's objections, involving in fact, as Captain Crofton says, *the* main point at issue, little more than two pages are devoted in reply. Indeed, the real gist of the reply is contained in a marginal note subsequently added; and we cannot but think it was a mistake not to have entered more fully into the important question raised; if necessary, by a separate Appendix; or else to have left it alone altogether, as foreign to the subject matter of the Report.

* At Mahmoodpore, in the left chamber, the floor, whose least thickness was 6 feet, was quite cut through, and a hole 15 feet deep eroded in the sandy substratum. At Jaolee, the brick-on-edge covering to the floor was in places bulged upwards, as if blown up from below, and water was seen to spout through the side walls 3 or 4 feet above the flooring.

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Sir Arthur Cotton's point was, as will be seen by turning to the former article, that the canal had been taken off at too high a point on the river's course, thereby having to run the gauntlet of the whole of the upper drainage of the Doab, whereas it should have been taken off at some lower point near Sookertal, below the junction of the drainage lines with the river. To this Captain Crofton replied, that the river bank at this latter point was too high and that the excavation of the Canal would have required a cutting of an average depth of 53 feet on a direct course of 57 miles, so that the earthwork alone would have cost more than 2½ millions sterling. But, as Sir A. Cotton had already said, that no such direct course would have been chosen, but a circuitous route under the high bank until the ground suited for piercing it at a small cost, Captain Crofton added a marginal note in reply, explaining that such a course would be impracticable on account of the difficulty of dealing with the drainage from above, and the necessity of carrying the canal for many miles in high embankment above the valley, which, for so great a body of water, could not be considered safe. Doubtless to Engineers acquainted with the locality such a course would be considered clearly out of the question, and if Sir Arthur Cotton had himself inspected it, he would probably have thought so too, but to those not on the spot his views merited, we think, at least a more careful and detailed reply than they received in this marginal note.

The Government apparently thought so too; for soon after the publication of Captain Crofton's Report, and on Sir Arthur Cotton's re-iterated assertions that his views had not been properly considered, it was resolved to appoint a Committee of experienced and impartial Engineers* to report on the whole question, and decide whether Captain Crofton's proposals should be accepted or whether further action should be stayed, "pending the preparation of a detailed project according to the views of Sir Arthur Crofton."

The only exception that can be taken to this course is, that as Sir

* Col. Lawford, Madras Engineers, *President;* Lieut.-Col. Anderson, Madras Engineers, Lieut.-Col. Fife. Bombay Engineers, Geo. Sibley, Esq., Chief Engineer, E. I. Railway, H. Leonard, Esq., C. E., *Members.*

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Arthur Cotton had never gone beyond an expression of views and suggestions, it would perhaps have been better to call upon him for a detailed project, to be prepared by himself, or some Officer nominated by him, and supported by plans and estimates, and *then* to have laid the two projects side by side before the Committee. As it is, the Committee have necessarily had to base their Report on Estimates which they have had to draw up for themselves,* and which necessarily are only approximate, and on data which were for the most part furnished by one side only. On the other hand, the preparation of such a detailed project must have involved considerable delay, and it was highly desirable that some definite decision should be come to without further loss of time.

The Report of this Committee has just been presented, and a more able and impartial document it would be difficult to find. A very careful examination was made of the whole country affected by the questions at issue, and the opinions arrived at show that those questions have been carefully considered under every possible phase, as well as that more immediately presented for solution. The conclusions finally come to by the Committee may best be stated in their own words:—

"I. That the construction of a weir across the Ganges below the confluence of the Solani, with other necessary works for supplying water to the canal, at an estimated cost of Rs. 1,12,86,314, cannot be recommended.

"II. That the project for opening an additional canal head, including the construction of a weir on the Ganges at Rajghat, or other point in that part of the river, at a cost of Rs. 1,13,04,170, for bringing under irrigation lands not now watered by the canal is feasible, but should be held in abeyance until the probable returns appear more proportionate to the outlay than at present.

"III. That the construction of a weir across the Jumna at Toghlukabad, with a canal for the irrigation of that part of the Doab below Allyghur, not under the influence of the Ganges canal, at a probable cost of Rs. 35,45,701, inclusive of branch channels, is practicable, and that the project should be further

* Sir Arthur Cotton has, indeed, already protested, in anticipation, against the Committee's Report, partly on this very ground; but his objections to its constitution, on the ground that no Officer representing his own peculiar views was upon it, seem unfair. The Committee were to sit as judges not as advocates, and the Government rightly replied, that he had the opportunity of stating his own case through Col. Rundall, who was known to hold the same views, and who had been invited by the Committee to accompany them in their inspection and assist them with his suggestions.

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investigated; but they are of opinion that it cannot be substituted for any portion of Major Crofton's project.

"IV. That Major Crofton's project for remodelling the Ganges canal should be proceeded with, subject to the modifications suggested in this Report.

"V. That the construction of a permanent weir across the Ganges at Hurdwar, though not indispensable while the present reduced quantity of water is passed down the canal, will become a matter of absolute necessity in order to maintain without risk of interruption the full supply of 7,000 cubic feet per second."

These conclusions are stated at the commencement of the Report, and the facts on which they are based are set forth in detail afterwards. An interesting account is first given of the physical peculiarities of the Gangetic Doab, which Sir P. Cautley and the Bengal Engineers have always maintained had a great deal to do with the argument at issue, but which Sir A. Cotton has always denied. These peculiarities, as distinguishing a Doab from a Delta, have already been described in the former article, and the only additional fact here elicited, seems to be that referring to the difference in the nature of the sandy beds of the Ganges and such rivers as the Godavery; the latter of which is described as a large coarse-grained sand, more nearly resembling gravel; while the Ganges bed consists of a fine powdery sand, which is much more liable to be acted upon by the current of the river. This is an important point as affecting the depth to which it would be necessary to sink the foundations of any weirs thrown across the Ganges, which the Committee think should be 15 feet deep (in lieu of the 6 feet wells that have been found sufficient in Madras rivers), even when protected, like them, by a long talus of stones on the down-stream side.

With regard to a weir at Sookertal, much stress is naturally laid on the distance of any adequate supply of material to form both the weir itself and the protective talus. The cut stone required would cost at least Rs. 2 per cubic foot. Blocks of concrete made from the shingle on the spot are recommended as the cheapest material that can be used for the principal part of the work, and they are estimated to cost about the same as brickwork, Rs. 20 per 100 cubic foot. The whole estimate for the weir itself amounts to 44 lakhs.

The most favorable course for the supply channel is then carefully

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indicated. It would run for 29 miles along the Khadir, or low land, being partly in cutting and partly in heavy embankment, and would then run through the high ground for 23 miles in heavy cutting; after which the excavation would be moderate as far as the junction with the present line. The total cost of the channel is estimated at 68¾ lakhs.

The entire cost, therefore, of such a head to the canal would be 112¾ lakhs of rupees; and as the headworks and channel, as executed by Sir P. Cautley have cost only 81 lakhs, it is evident that the balance of cost is greatly in favor of the scheme actually carried out. Moreover, the first sum is only an *estimate*, and from the difficulties of the work, as explained by the Committee, it would not unlikely be greatly exceeded in actual practice.

The possibility of a weir lower down at Rajghat is then canvassed, the only essential difference between this and the higher site being, that block kunkur is available for the work at a distance of some 14 miles.

At Toglukabad, however, on the Jumna, a little below Delhi, a weir is considered practicable, mainly on account of the proximity of abundance of stone; but it is so low down that such a site could merely be looked upon as a feeder for the lower branches of the canal, and would not at all take the place of works required for the supply higher up. Mr. Sibley so far dissents that he would, however, look upon this as *the* source of supply for the lower portion of the canal, leaving the upper portion to carry its present (short) supply without any alteration. But the rest of the Committee dissent from this view, and Mr. Sibley only states his opinion with the proviso that the quantity of water available from the Jumna in the dry season shall be found to approximate to 3,000 cubic feet per second, an amount which does not appear likely to be realized.

As to the present condition of the canal, the Committee entirely concur in the view taken all along by the Canal Officers, that its one fault is in the too great declivity of the bed; but they remark with surprise, that after all the fault found with it, "it has been carrying nearly two-thirds of its full supply for the past 20 months, and that the navigation, though imperfect, has been going on

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without interruption for the same period, during which the canal has not been closed for even a single day," while "the area of irrigation has steadily increased year by year." * They then proceed to criticise Captain Crofton's project for the remodelling, and while generally agreeing in the measures proposed, and deprecating any false economy in such an important matter, suggest a reconsideration of some of the details, as involving changes which seem unnecessarily expensive.

The Committee think that it would be possible to execute that portion of the new works below the water-line in two short closures of 3½ months each, by which the loss of revenue would be slight, but Mr. Sibley dissents from this opinion, and the time certainly seems very short, especially when the difficulty of laying the foundations dry in the first instance is duly considered.

The importance of a permanent Weir for the canal head at Hurdwar in then alluded to; though, as is acknowledged, the subject has for some time engaged the attention of the local Canal Officers.

With regard to the Hurdwar stone, of which so much has been said, the Committee "are satisfied that although stone of good quality may be obtained in small quantities, scattered over the hills, yet there is apparently no single spot where quarries can be opened with the prospect of an abundant supply being met with." Further search, however, is recommended in the main range of the Himalayahs, but it is evident that even with water carriage from Hurdwar, the cost of working and expense of land carriage from the quarries will raise it to a very high rate per cubic foot, far exceeding the most expensive brickwork.

A very interesting Memorandum is appended on the Financial State of the Canal, showing that even in its present undeveloped state, the net proceeds for the past Financial year have returned 3½ per cent. on the total cost; or, if the approximate estimate of increase to Land Revenue be added, not less than 5 per cent. At the same time, attention is drawn to the fact that the original object of Government in sanctioning this work was not so much to form

* The total receipts for 1865-66 are Rs. 13,39,047.

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a source of revenue from the price paid for water, as to have a guarantee against the recurrence of famine and failure of the land revenue, while the general improvement of the country was looked to to repay the outlay indirectly. Hence the low water-rates charged, the returns from which have alone been credited to the canal; while the Committee quite concur with Col. Dyas, that the enhancement of the land revenue should be as clearly shown on the profit side of the account. Calculations are then gone into to show, that as soon as the full supply can be passed down, and the system of irrigation fairly developed, so that the water may do the same amount of work which it does steadily on the Jumna Canals, the net returns will not only suffice to pay 5 per cent. on the total cost, "but to pay off the accumulated interest of former years; and that once effected, to yield a clear profit of 8 per cent. per annum, *exclusive* of the enhancement of land revenue." "Considering therefore all the circumstances noticed above, which have hitherto tended so materially to frustate the success of the Ganges Canal in a financial point of view, the Committee are of opinion that its comparative failure up to the present time, affords no ground for doubt of a fair and reasonable return from other irrigation projects, constructed with the express object of yielding a direct profit." Such an opinion, formed carefully from actual data, by a Committee of impartial men, cannot but be considered as in the highest degree satisfactory and encouraging in regard to future schemes, which have doubtless been suspended while the Ganges Canal has been as it were on its trial.

Some remarks are made in explanation of the difference of Financial results in the case of Madras and Bengal irrigation works, and as this is a subject that has been greatly misunderstood, we have though it best to give Col. Anderson's note on the subject at full length, in another part of this number.

The Committee rightly lay stress on the importance of a system being devised as soon as possible for distributing the canal water by measurement, and not charging for it by the area irrigated. They point out that the present method tends to extravagance in the

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consumption of water, and hence of course to loss of revenue. The late Col. Baird Smith, it is well known, was strongly in favor of such a system being adopted, thinking rightly that on a new work like the Ganges canal, where no previous system had to be overturned, it was advisable to persevere in introducing a more scientific system, even at the risk of the irrigation being more slowly developed.

This principle has, however, we believe, since been abandoned; the old system of area measurement found more favor with the people; and, undoubtedly, since the contract system has been generally abandoned, the annual revenue has increased very rapidly. There is too, of course, the practical difficulty that no satisfactory pattern of water module has yet been devised, which shall be economical and efficient, and not likely to get out of order. But it is difficult to conceive, that if a liberal reward were offered, mechanical skill would not be found sufficient to overcome the difficulty, and we cannot but think that, meanwhile, the roughest approximation to accuracy would have been preferable to the present system which wastes water, involves the keeping up of large establishments, and entails enormous labor on Canal Officers,* even if it does not open the door to peculation more than the other.

We must now leave this very interesting Report, trusting that Government will extensively circulate it amongst Irrigation Officers; and though it is to be feared that some extreme partisans may not be satisfied with the opinions set forth, we believe that the verdict so carefully given, will be accepted by the profession and the general public, as a satisfactory settlement of the points in controversy.

J. G. M.

* There is no more reason why a Canal Engineer's time and professional experience should be employed in questions of Revenue and disputes about water, than that the Engineers of a Railway, when once made, should be employed in looking after the traffic.

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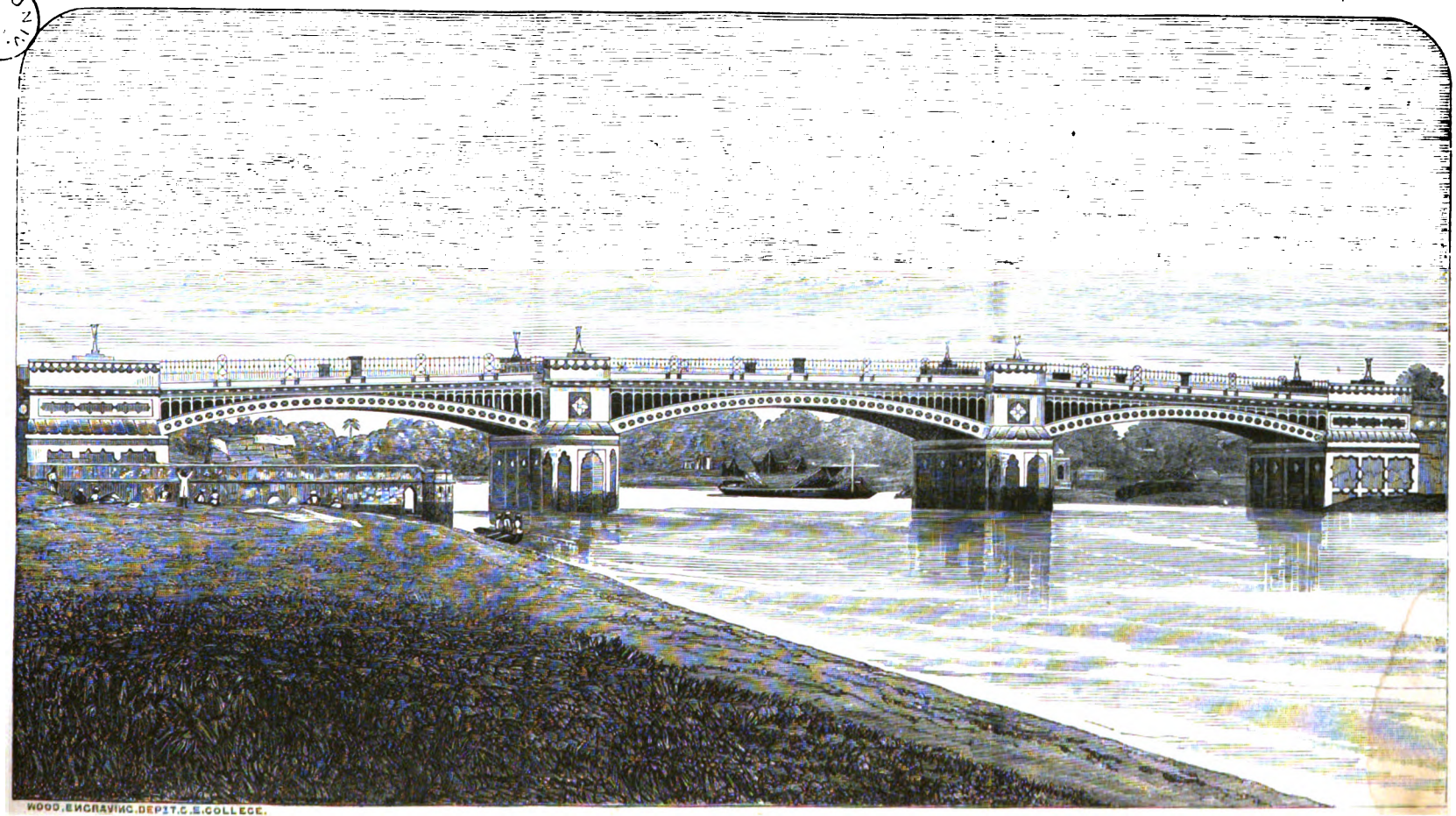

IRON BRIDGE OVER THE GOOMTEE—LUCKNOW.

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No. CXX.

IRON BRIDGE OVER THE GOOMTEE—LUCKNOW.

This graceful structure, of which an Engraving is given in the Frontispiece of the present number, consists of three cast-iron arches supported on piers and abutments of brick masonry, the centre arch having a span of 90 and a rise of 7 feet, while the two side arches have spans of 80 feet, and a rise of 6 feet. The iron work was received from England in 1798, during the reign of Nawab Saadut Ali Khan, only twenty years after the erection of the first iron bridge in England, General Martin, who was then living at Lucknow, having it is supposed suggested the idea to the Nawab.

The bridge was designed by Rennie, being very similar to one erected by that famous Engineer over the Witham, at Boston, in Lincolnshire. The iron work remained unused at Lucknow *more than forty years*, when the bridge was at length erected by Col. Fraser, Bengal Engineers, between the years 1841-44; the cost of the masonry and erection having been Rs. 1,80,000; the cost of the iron work is not known.

The foundations are sunk on wells in the usual way. The width of roadway is 30 feet, and its height above watermark at the centre is 35 feet.

W. D. B.

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No. CXXI.

THE HASTINGS' SHOAL.

Report upon the Hastings' Shoal in the Rangoon river. By Hugh Leonard, Esq., M.I.C.E., F.G.S., *Superintending Engineer.*

The impediment on which a report is required being a local one, confined to a single spot in the Rangoon river, and directly affected by local causes only, it does not seem necessary to write a long or general description of the rivers by which it is formed; it will be sufficient, and most likely better adapted to the end in view, to consider only such facts as bear directly, either upon the formation of the impediment, or upon the work considered necessary for its removal. Neither does it seem necessary nor even desirable, to enter upon any lengthened consideration of the value to the port of the removal of the impediment; indeed, considering the rapidly increasing importance of Rangoon, it would be difficult to estimate it. The officers of the Local Government are the best judges of this part of the question, and no doubt it will be carefully considered by them. The report will therefore, be confined to facts bearing directly on the best and most economical means of removing the impediment, and of keeping the channel clear when opened.

The town of Rangoon is situated about 30 miles from the Gulf of Martaban, on the most eastern offshoot of the Irrawaddy river. This offshoot is the fine navigable channel known as the "Rangoon river." A mile or two below the town, the river is joined by a branch known as the "Pegu river,"—a channel about as large as the Rangoon. Through the land situated between these two rivers, a third flows, joining them at the very

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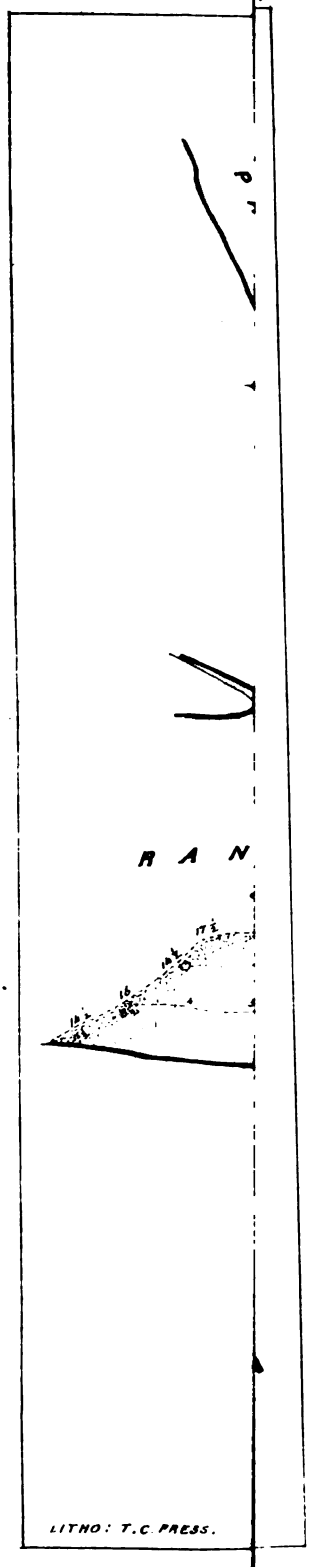

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point where they meet; this is known as the "Pussendoon creek;" it is very small when compared with either of those which it joins. Just above this point of triple junction in the Rangoon river, the "Hastings' Shoal" is situated. (See plan).

From the Gulf of Martaban to the Hastings' Shoal, there is a very fine navigable channel, varying from a mile to half a mile in width, with ample water at every stage of the tide for any class of vessel. Immediately below the Hastings there is five fathoms, a little further up it shallows to one and a half, then to one, and this state of shoal water is carried,—measuring along the track which ships usually take,—for about a mile. The shoal is nearly the same height from bank to bank, having from 6 to 7 feet in it at low water springs. It varies much in length; near the left bank, it is not more than one-third of a mile long; in mid-channel it is more than a mile; and on the right bank, it commences at a point about a mile above the Pegu river, and extends for several miles down-stream, joining on to the "Liffey Sand." The rise of tide at Rangoon is about 20 feet in springs, and about 12 in neaps; so that generally, even at neaps, most ships can get over at high water; while during springs, any vessel trading to Eastern ports can cross. The inconvenience caused by the shoal is *delay* in entering the port; it does not shut any vessel completely out. The current during spring-tides is sometimes as much as four and a half knots an hour; during neaps it is not more than two knots. There are strong freshes down the Rangoon river, so strong as to prevent ships from swinging to the floods; but on the Pegu river, ships always swing.

The shoal seems to be formed of fine sand covered over in places with a thin coating of mud. The following are the data from which this conclusion is drawn. The surface of a sand, which is a continuation of the of the Hastings, was carefully examined at low water. An iron rod was run down in the tail of the shoal to a depth of 15 feet below low water. The Captain of the Steam Tug *Vulcan*—who is said to know more about the "Hastings" than any one in Burmah—states, that he has known a channel 18 feet below low water to have been scoured out after a heavy fresh. Such data are tolerably convincing, quite enough so for the present purposes of this report; but if works are to be carried out, a much more careful examination must be made before commencing them. The nature of the examination necessary will be described further on.

There are undoubtedly, ample grounds for concluding that the cause of

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the formation of the shoal is the action of the water of the Pegu on that of the Rangoon; both theory and experience point very decidedly to this conclusion. The Pussendoon creek has some slight influence on the action of the two rivers; but it is so slight, it may be neglected in the examination of the question. A river carries silt on account of the force of its current being strong enough to move particles of matter either in suspension or rolling along the bed, a certain strength of current moving matter up to a certain size. If the velocity of the current be diminished some of this matter will drop or stop moving, and where it stops, a shoal will be formed. There are many movements in rivers by which the velocity of the current may be diminished; one is, that if two streams, moving in different directions, strike against each other, the velocity of one, or of both, must be diminished,—the laws governing them being the same, within certain limits, as those governing other bodies in motion under similar conditions. The greater the angle between the two streams, the greater the disturbance and check caused by their junction. Now, in the case under consideration, the Pegu rushes into the Rangoon; they strike each other at a very bad angle, consequently, a great disturbance and a diminution of velocity in one or both must follow. The Pegu passes a greater volume of water than the Rangoon; the current of the latter gives way, the velocity is diminished, silt is dropped, and the Hastings' Shoal is formed. This is the theoretical view of the case. The practical view is, that it is a well known fact that wherever two rivers meet at a bad angle, if either, or both, be silt bearers, there is always a shoal above the point of junction in one, if not in both; the size and position of the shoal depending on the relative size of the rivers, the silt which they carry, and the angle which they form near the point of junction. For instance, the Roopnarain river falls into the Hooghly, which it meets at about right angles; it is a larger river than that into which it falls; both carry a large quantity of silt, the result is a very bad shoal in the Hooghly above the point of junction. Again higher up, the Damoodah also falls into the Hooghly; but the Damoodah is the smaller of the two, and they form a much smaller angle at the point of junction than that formed by the Roopnarain and the Hooghly; the result is a shoal above the point of junction: but it does not extend across the river, and causes little inconvenience compared with that formed by the Roopnarain. The Pegu and the Rangoon act very much like the Roopnarain and the Hooghly; the result in

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one case is the "Hastings' Shoal," in the other the James and Mary Sands. In addition to the fact that the Pegu passes more water than is passed by the Rangoon, there are two reasons why the shoal should be in the latter river. First, the Rangoon carries much more silt than the Pegu; consequently it contains one of the elements necessary for the formation of shoals to a much greater extent, and hence the shoal is more likely to be formed in it. Next, the Rangoon widens just above the point where the Pegu joins it. The Pegu does not widen at the junction, so that the water of the Rangoon has more room to spread; spreading tends to slacken the current, and consequently to form the shoal. It is not at all improbable that the widening of the Rangoon may be the *result* of the shoal, and not its original cause: but, be that as it may, the effect of the widening now, is to keep up the shoal.

If the only point for consideration in designing works for the improvement of the river were, how to form a channel through the shoal as it now stands, it is quite certain that the simplest and the cheapest way of doing the work would be to *dredge*—the undertaking would be neither difficult nor gigantic. But it is extremely probable that if a channel were dredged out, the agency which formed the shoal would fill it up again, and that too, very rapidly. It is known (information received from the Captain of the *Vulcan*, already referred to) that a channel has been formed—scoured out by a heavy fresh in the river, once at least—and that it filled up again as soon as the dry season set in: now, if this channel, formed by the action of the current, filled up so quickly, it seems reasonable to conclude that an artificial one, however made, would not remain longer open. The quantity of silt carried by the river even now—the month of February—is very large, it would be difficult to ascertain at what rate it would deposit in a channel while being dredged or when finished; but there seems to be every reason to fear, that it would deposit faster than a very powerful dredger could take it out. A machine costing about two lakhs of rupees would take fully two years to dredge a channel 600 feet wide, 3,000 feet long, and 15 feet deep,—as small a channel as it would be desirable to confine a project to,—and this it appears would silt up in one year; if so, it would take two such dredgers to keep the channel deep, even after its formation. There seems to be but one condition under which a resort to dredging, without other works in connexion with it, could be recommended. It is this; Captain Williams, who was Executive Engineer of Rangoon for some years,

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and who understands thoroughly the requirements of the place, states, that it is of great importance that a large quantity of low-land along the river edge should be raised, and he thinks, that the best, if not the only means of getting materials to raise it, is by dredging in the river. Captain Oliphant, the Chief Engineer, is understood to be of the same opinion. Now, if this view be correct, and that it be considered worth while to employ a steam dredger to get materials to raise the ground, then decidedly one should be purchased and set to work to dredge a channel through the part of the shoal which would be most likely to remain open. In this way, it might be settled whether it is possible to dredge a channel, and to keep it deepened or not; the question would be practically tested in a very satisfactory manner, without any unprofitable outlay. If it *be* decided to dredge, the following particulars will be of use. The best line to follow in dredging a channel, is marked on the plan:—A good dredger should put the material into barges, at a cost of about one rupee per 100 cubic feet; every expenditure, save the cost of plant, included. The best class of dredger for such work is a "double dredger," with ladders at the sides, protected by framing; engines 20 horse-power, nominal; self-acting gear to move vessel fore and aft, and transversely; ladders to work in 30 feet of water. The best place to have her built is in the Clyde. The cost in Moulmain should be about two lakhs of rupees.

But, for the deepening of the shoal, and the permanent maintenance of a channel through it, apart from such considerations as have been discussed above, the main works must be designed with a view to the removal of the *cause* of the impediment. If the reason already given for the formation of the shoal be correct, the aim of any work designed for its removal must be to prevent the Pegu waters from entering the Rangoon at such an angle as they now do—cutting them off altogether being an impracticability. Although rivers injure each other so much when they unite so abruptly, they would do comparatively little harm if they joined when forming a very sharp angle, that is when running in nearly the same direction. The effect of such an arrangement can be well understood by observing the movements of bodies afloat on rivers. If two vessels moving at right angles to each other were allowed to strike when moving rapidly, without altering their courses, the result would be great injury to one or both: but if they were made to curve round as they approached, and were only allowed to touch when they had taken the same, or nearly the same course,

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little if any inconvenience would be felt. So it is with bodies of water if they strike when running at right angles to each other, great disturbance, loss of velocity, and the formation of a shoal is the result; but if one or both be trained round by banks or other works until they run nearly parallel to each other, they may join and run together without any great disturbance of either. The blue arrows on the plan show how the Pegu runs into the Rangoon now,—it drives the Rangoon water right across the channel, completely changing its course and regimen; the red arrows show how it *should* enter in order to fulfil the conditions just explained. If the two rivers can be made to take the courses shown by the red arrows, they will have little, if any, further tendency to damage each other; and the nearer they can be brought to this course, the less will be the injury arising from their junction. In addition to directing the course of the currents by the works at Pussendoon creek, two alterations are desirable,—to narrow the Rangoon river at the shoal, by bringing out the right bank so as to keep the water from weakening its scouring power by speading over the shoal; and to widen the Pegu river, by cutting off some of its left bank, and so allow the water to pass without pressing too hard on the spur works at Pussendoon. The portion colored light red on the plan, shows the form which the banks should take in order to produce these results.

There is every reason for believing that, if the rivers be shaped as now proposed, no shoal would ever form at their point of junction; but it is not so certain that a current will be produced sufficiently strong to remove the present shoal without some other aid. There are, however, strong grounds for believing that even this will be effected,—one is, that the sand forming the shoal is so fine, and consequently so easily removed, that a very slight increase of current will do it; another is the fact, that an increase in the fresh water discharge down the Rangoon river, really did wash some of it away, although the current was not confined within proper limits, nor was it well directed. However, if the works alone will not remove the shoal, they will certainly do so if the surface be stirred up and put slightly in motion. They will have the effect of making the current on the shoal as strong, and as regular as it is above it, and so, the only reason why it should not move the sand there, as it does above, is that it may have become consolidated since it was dropt; if it has, some artificial means of loosening it must be adopted.

The class of works which will best economically accomplish the object in

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view is a point requiring much consideration. It is evidently impracticable to shape the banks, as desired, by filling and forming them by labor alone. The least expensive way of doing it, is by constructing works which will tend to produce the desired result, by checking the current, collecting silt, and thus forming up the banks from the vast quantity of material carried by the river itself. The plan which seems best adapted for this purpose is the construction of two strong spurs to form the main barrier to the current, and the core from which to extend small works to collect silt to complete the form. These spurs are shown in the plan in dark red, the most important of them that on the Pegu side, will be a heavy work, owing to the depth of water in which it must be built. As shown on the plan, about 1,200 feet of it will be in water of from four to five fathoms; there does not, however, seem to be any better or more economical way of doing what is required. The spur on the Rangoon side is in comparatively shallow water, and will be neither difficult nor expensive to construct. These two large works should be first constructed, then small ones thrown out from them to form up the banks by the collection of silt to the shape shown on the plan. The small spurs shown on the plan, both on the Rangoon and Dhallah banks, are drawn merely to give an idea of what is intended; the experience gained in the construction of the main works and the result of their action, will be the best guide in fixing the position of the minor ones.

In considering the form which the works should take, their effect on the Pussendoon creek has been carefully considered, as it is known to be a very valuable auxiliary to the port. The tendency of those described will be to improve the creek,—the double spurs protect it from being crossed by the currents of either river, the flood tide will have a more direct run into it, consequently more water will flow up, and a good flood always return a good ebb scour; both flood and ebb would be well directed, so that there is every reason to believe that the entrance to the creek will be improved.

It has been noted that the width of the river at the shoal helps to maintain the impediment; there also seems to be a tendency just now, to form a kind of back channel on the right bank. This is a decided evil, any channel formed there would never be a good navigable track; a bad one would be useless, and it would tend to neutralize the effects of the works on the opposite side; hence it is decidedly desirable that this back channel should be closed, or at least prevented from enlargement. The best way of

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closing it will be to throw out a spur or spurs, from the bank, near the commencement of the shoal to turn the current out towards the centre of the river. Large or very permanent works, will not be required; something to train the current gently away from the bank to commence with, then, as a shoal forms by the obstruction, gradually extend the work,—outward and downward, as may be required. By following up a systematic plan of this kind, the bank may be easily brought out to the shape desired.

It is probable that, as soon as the spur which is to be thrown out from Pussendoon point begins to act, the current will press hard on the opposite bank of the Pegu, and thus wear off the corner which is to be removed. If the current alone will not cut it off, other assistance must be given. Excavating it even to low-water mark would be a very expensive work; before attempting it, every means of aiding the current to cut it should be tried. Anchoring boats along a bank, within 10 or 12 feet of it, very often causes rapid erosion; this should be tried as far as practicable; the boats employed on the works might be made to use the site as anchoring ground as often as possible. Next, the hardest bits of the earth forming the face of the bank might be excavated. Lastly, if more be necessary, a narrow slip along the whole face might be cut away, leaving the bank as nearly perpendicular as possible, so that when the current acted on it, it might tumble in.

The material to be used in the construction of the works is of course a matter of great importance. Indeed, if there were not considerable facilities for collecting it on unusually moderate terms, the works proposed would be so costly, as to deter many from undertaking them at all: everything required, however, is easily obtained, and comparatively cheap. For the deep-water part of the two large spurs, stone is decidedly the best material to use; timber of the length required is very expensive, and so is labor to fix it; stone, on the other hand—within certain limits as to quantity—is easily procured and unusually cheap. The Master Attendant states that, at least 30,000 tons per annum of ships' ballast, can be dropt on the site of the proposed works at the rate of eight annas a ton; if so, there can be no doubt whatever that it is the cheapest and best material to use for all works, in water of more than two and a half fathoms. It is not at all certain that it is not cheaper for works in much *less* depth, but there are decided advantages to be gained from using more than one kind of material. First, the quantity of any one kind available will not be enough

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to allow of the works being carried out rapidly, and rapidity with works of this class, means economy. Next, a sufficient number of boats adapted for conveying ballast could not be had without a very large outlay for plant. Again, by using different kinds of material, different kinds of labor will be brought into use, permitting the works to be carried on rapidly without great pressure on any one class; and, lastly, by this means, experience will be gained, while the work proceeds, as to which class of material is best adapted to the end in view, both in point of economy and of time. This last reason is not the least important; for there is no rule which is applicable to all cases, under all circumstances; and the experience gained from close observation during the progress of a work of this kind, is often worth more than the best professional opinion. With this reservation, the following general rule may be adopted:—For works in depths of over 2½ fathoms, use the largest stone ballast available; small stone, used merely to fill up the interstices between large ones, being useless—wasted in fact. The base of the spur may be laid out a few feet more than double the height; the stones will stand well at slopes of 1 to 1, and there is no necessity for more than a few feet in width at top. In depths of from one up to two and a half fathoms, ordinary guide and sheet-piling, like the sides of a common cofferdam, with a line of brush-wood about 6 feet wide and 2 feet deep sunk on either side, to prevent washing about the feet of the piles. In depths of less than one fathom, two rows of jungle-wood piles, driven at distances of about 3 feet apart each way, the space between being filled in with brush-wood secured down with clay, or stones, &c.

As the depth of water in which the large spurs must be built is considerable, it will be necessary to adopt every available means which may be likely to economize material; the following plan has often been found to effect a great saving. The spur should at first be laid out only large enough to allow of its being carried up to the level of low water; as it will generally be found that, when the stone-work is carried up to this level, a shoal will be formed on one side, or, perhaps, on both sides of it. When the shoal is completely formed to the level of the spur, a line can be set out on the shoal and old spur, of dimensions sufficient to allow of its being carried up to half-tide level. Half-tide level will generally be found high enough to carry the stone-work; but if, when the shoal forms up to this level, more be found necessary, another can be laid to be carried up to

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ordinary high-water. By proceeding in this way, a very great saving may be effected if the scheme be successful; while, if it fail, that is, if silt do not accumulate as the work proceeds, the worst that can happen is, that the spur must be carried up as it would have been if the attempt had not been made.

When building in currents, the site of the spur should be covered *completely over* with about a foot deep of small stones, or very coarse gravel, before any part of the work be carried up more than a few feet in height. This precaution is necessary whatever kind of spur be used: if it is not attended to, the current, which always runs round the spur-head, will deepen the site of it as the work proceeds, so that a work which was intended to have been in 10 feet of water may be really carried out in 20. The deepening goes on gradually and almost imperceptibly: but the loss of material caused by it is often very great. In the case of small pile and brush-wood spurs, the piles may be all driven first, and then a thin layer of brush-wood put over the bottom, before any part of the body be raised.

It has been already explained, that the data on which an opinion has been formed, as to the nature of the materials in the shoal, are not sufficiently accurate to warrant the commencment of works; it is possible that there may be some hard material in some part of it which could not be removed by the means proposed. In order to settle this part of the question conclusively, a set of borings should be made in the positions shown on the plan: they should be carried to a depth of four fathoms below low water. The work is not difficult; all the apparatus required for it is in store at Rangoon. If only sand be found, borings on the sites marked on the plan will be sufficient; but if laterite, or any other hard material, be found, as many additional borings must be made as will fix accurately the position and extent of the hard spots. If there be hard material enough to affect the scheme of improvement proposed, the question must be re-considered. It is, however, all but certain that the whole obstruction is formed of sand alone.

The survey attached to this Report is not sufficiently detailed, nor sufficiently extensive to answer for a working plan. It is quite possible that a better plan may show that some modification of the details of the design, now submitted, may be an improvement: the main features, however, would remain unaltered. Mr. Pearson is now making a survey of the

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river, so that there is a very favorable opportunity of getting a good plan of the shoal. He should be instructed that an accurate survey of the Hastings' Shoal is required: it should take in the shoal, a distance of two miles above, and the same below "Monkey Point," a distance of two miles over the Pegu river, and of one mile up Pussendoon creek. The banks should be accurately fixed, and the lines of soundings on his survey should be referrable to fixed points on the banks. The soundings should be within distances of 200 feet of each other, and very accurate in the lines of the works, as laid down on the plan. The survey should be plotted to a scale of 1,000 feet to an inch. The work, as laid down on the plan attached to this Report, should be transferred to Mr. Pearson's survey, so that any modifications considered necessary, owing to a difference in the surveys, may be made.

ESTIMATE OF THE COST OF CARRYING OUT THE PROPOSED WORKS.

	RS.	RS.
Spur at Pussendoon point—		
Stone ballast, 80,000 tons, at 8 annas, ... =	40,000	
Gauge and sheet piling, 400 l. ft., at Rs. 10, ... =	4,000	
Small spurs for silting up, 5,000 l. ft., at Rs. 1. .. .. =	5,000	49,000
Spur at Monkey Point—		
Stone ballast, 40,000 tons, at 8 annas, ...	20,000	
Gauge and sheet piling, 600 l. ft., at Rs. 10, ...	6,000	
Small spurs for silting up, 5,000 l. ft., at Rs. 1, ...	5,000	31,000
Silting up the back Channel—		
Stone ballast, 10,000 tons, at 8 annas, ...	5,000	
Gauge and sheet piling, 1,000 l. ft., at Rs. 10, ...	10,000	
Brushwood spurs, 5,000, at Rs. 1, ...	5,000	20,000
Cutting away Pegu Point—		
Say		10,000
		1,10,000
Contingences, 20 per cent., ...		20,000
Total, ..		1,30,000

CALCUTTA,
March 8th, 1866.

NOTE.—This estimate does not profess to show more than a general average cost. The work should not cost more.

H. L.

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No. CXXII.

STRESSES ON LATTICE GIRDERS.

(2ND ARTICLE).

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

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

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

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

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

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

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

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

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for the other bar of the "pair;" that is, the bar meeting the bar examined at the unloaded chord.

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

W_b = the bridge or permanent load at each apex.

W_p = the passing or travelling load at each apex.

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

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

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

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

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

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

and hence—

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

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

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

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

The bridge load will consist of:—

1. The girder weight for ordinary spans, usually between 50 to 500 lbs. per running foot.

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2. The platform weight, for ordinary spans, usually between 20 to 30 lbs. do.

3. The metalling or ballast depending on depth used, 100 to 120 do.

4. A body of men, such as a crowd, 70 to 80 do.

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

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

$w_b = 50 + 190\ b$, and $w_b = 500 + 230\ b$; in which

b = the breadth of platform to be supported by girder.

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

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

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

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

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

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

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

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

It is assumed in the above that, to avoid cross strains on the material of the chords, the transverse girders, which carry the load of the roadway are only to be placed at the apices of the latticing of the main girders; and, consequently, λ, the distance apart of the roadway girders = the length of opening of the "bays."

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

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

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

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

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

therefore $\Sigma = \frac{2S}{m\lambda}$ ..... (6)

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

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

and so on.*

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

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

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

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and there still remains the objectionable length of unsupported strut in the case of the compression bars.

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

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

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

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

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

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

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

If, therefore, we use formula 1*a* in this instance—because 7·143 is not a convenient number to work with—we have the following data—

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

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

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

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

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

Formula 1*a* becomes ·84 N (N − 1 + x).

Thence we obtain the maximum stresses on each bar, which would be

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caused by a series of weights, W_{bp}, on the girder; as shown in columns 6–7 of the annexed Table.

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

Again, the differences of the maximum bar stresses, $T_{bp} - T'_{bp} = T_{bp} - c_{bp}$, multiplied by 2 sin 45° = 1·414, gives the stresses on the chords due to the total loading, as shown in columns 14–15; and the sum of these stresses up to the required bay commencing from the end of the girder, gives the stress on the bay in question, as shown in columns 16 and 17.

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

26	„	„ 3
24	„	„ 5
&c.,	&c.,	&c.,

and we write these tensions in the table.

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

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

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

38. We have now in this Table the stresses on all the chief parts of the

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girder, and it remains only to determine the scantlings of the iron by which these stresses are to be resisted.

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

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

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

f_t, the modulus for tension.
f_c, „ „ compression.
f'_t, the working stress for tension.
f'_c, „ „ compression.

Rankine makes, $f_t = 60{,}000$ lbs. $f'_t = 10{,}000$, or $4\frac{1}{2}$ tons nearly,
$f_c = 36{,}000$ lbs. $f'_c = 6{,}000$, or $2\frac{3}{4}$ do., do.,

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

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

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

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

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

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

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

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

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Abstract of Table of Stresses in Example Girder.

Members of girders.	Numbers on the diagram.	Greatest stresses in tons.	f_t.	Areas, square inches.	Scantlings, inches.	Remarks.
Tension Bars. Those sloping down and towards centre.	1	41·16	5	8·23	2 bars $6\frac{3}{4} \times \frac{5}{8}$	
	3	35·28	„	7·06	„ $5\frac{3}{4} \times \frac{5}{8}$	
	5	29·82	„	5·96	„ $4\frac{3}{4} \times \frac{5}{8}$	
	7	24·36	„	4·87	„ $4 \times \frac{5}{8}$	
	9	19·32	„	3·86	„ $3\frac{1}{4} \times \frac{5}{8}$	
	11	14·28	„	2·86	„ $2\frac{3}{4} \times \frac{5}{8}$	
	13	9·66	„	1·93	„ $2 \times \frac{1}{2}$	Packing pieces $\frac{1}{4}$ inch thick will be required here.
Bottom Chord.	VIII	49·88	„	9·98	Plates* $24 \times \frac{1}{2}$	† This plate is a little stronger than necessary, as it has to resist a shearing stress due to half the weight of beam.
	IX	91·45	„	18·29	‡ In addition to 4 L irons, 4 × 3 × $\frac{1}{2}$ running along chord. „ $24 \times \frac{1}{2}$	
	X	124·71	„	24·94	„ $24 \times \frac{3}{4}$	
	XI	149·65	„	29·93	„ 24×1	
	XII	166·27	„	33·25	„ $24 \times 1\frac{1}{4}$	
	XIII, XIV	174·58	„	34·92	„ 24† $\times 1\frac{1}{4}$	
Compression Bars. Those sloping down and away from centre.			f_c			
	2	35·28	4·5	7·84	2 L irons $6 \times 4 \times \frac{5}{8}$	With cross latticing. In these three bars we make very little allowance for the resistance of the inner flanges of the L irons, but which of course take much of the strain.
	4	29·82	„	6·62	„ $5 \times 4 \times \frac{5}{8}$	Do.
	6	24·36	„	5·41	„ $4 \times 3 \times \frac{5}{8}$	Do.
	8	19·32	„	4·29	2 bars $3\frac{1}{2} \times \frac{5}{8}$	This might perhaps better have been an L iron $3 \times 2 \times \frac{5}{8}$.
	10	14·28	„	3·17	„ $2\frac{3}{4} \times \frac{5}{8}$	
	12	9·66	„	2·14	„ $2 \times \frac{5}{8}$	
	14	5·04	„	1·12	„ $2 \times \frac{1}{2}$	Packing pieces will be required here.

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

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Members of girder.	Numbers on the diagram.	Greatest stresses in tons.	f_t	Areas, square inches.	Scantlings, inches.	Remarks.
Top Chord.	I	58·20	f_c 4·5	12·93	Plates * 24 × ½	† Of these 4 L irons we only include the top flanges = 6 square inches, in the area to resist the horizontal stresses in the chords, the vertical flanges go as stiffening and for excess of strength.
	II	108·08	„	24·01	„ 24 × ¾	
	III	149·65	„	33·25	„ 24 × 1½	
	IV	182·91	„	40·64	„ 24 × 1½	
	V	207·85	„	46·18	„ 24 × 1⅞	
	VI	224·47	„	49·88	„ 24 × 1⅞	
	VII	232·78	„	51·72	„ 24 × 1⅞	

† In addition to 4 L irons 4 × 3 × ⅜ running along chord.

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

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

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

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

36. It is also well, as far as possible, to maintain an uniform thickness of bar, so that there may be no necessity for packing pieces between the angle irons, which connect the bars with the plates of the chords; these

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

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pieces tend to lengthen the rivets, and so weaken them, and merely add useless weight to the structure.

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

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

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

The girder weight = 300 lbs. per foot run, and
The roadway platform = 30 „ square foot.

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

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

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

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

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

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

Total cubic feet, ... 632·7

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

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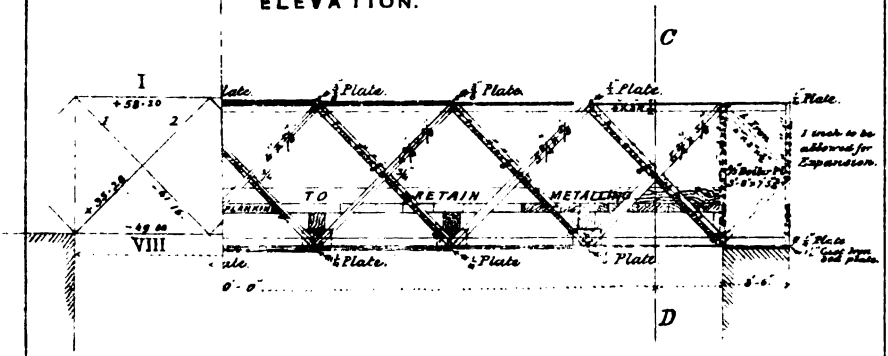
ELEVATION.



Note.— The thickness of Planking
ss of Planking designed is such that its Maximum deflexion will not
ft run.—
ams of Roadway are such that their Max: deflex[n] will not exceed 1½ in the Centre.

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

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

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

39. We do not—at least for the present—enter into practical details connected with the construction of girders; such as, "punching," "rivetting," "cover plates," "transverse bracing;" nor into the subject of "roadway platforms and cross beams." We have in our design used timber in this part of the bridge as being the most simple; but we might have adopted plate or lattice iron girders instead of the beams; and "buckled" plates instead of the planking, with considerable advantage, on the score of their greater durability.

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

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

JOHN H. HART.

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

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

Breadths of bars in inches.	Thickness of bars in inches.							
	⅛	¼	⅜	½	⅝	¾	⅞	1
	Areas in inches.							
1	·125	0·25	·375	0·50	·625	·75	·875	1·00
1⅛	·1875	0·375	·562	0·75	·9375	1·125	1·3125	1·50
2	·25	·50	·75	1·00	1·25	1·5	1·75	2·00
2⅛	·2812	·562	·843	1·125	1·406	1·6875	1·968	2·25
2¼	·3125	·625	·937	1·25	1·562	1·875	2·187	2·50
2⅜	·343	·6875	1·03	1·375	1·718	2·0625	2·406	2·75
3	·375	·75	1·125	1·5	1·875	2·25	2·625	3·00
3⅛	·406	·81	1·219	1·625	2·031	2·4375	2·843	3·25
3¼	·437	·87	1·312	1·75	2·187	2·625	3·062	3·50
3⅜	·47	·937	1·405	1·875	2·343	2·812	3·281	3·75
4	·5	1·000	1·500	2·000	2·500	3·00	3·500	4·00
4⅛	·531	1·062	1·594	2·125	2·656	3·1875	3·718	4·25
4¼	·562	1·125	1·68	2·25	2·812	3·375	3·937	4·50
4⅜	·593	1·187	1·781	2·375	2·968	3·5625	4·156	4·75
5	·625	1·25	1·875	2·5	3·125	3·75	4·375	5·00
5⅛	·687	1·375	2·062	2·75	3·4375	4·125	4·812	5·50
6	·750	1·5	2·25	3·00	3·75	4·5	5·25	6·00
6⅛	·8725	1·625	2·437	3·25	4·062	4·875	5·687	6·50
7	·875	1·75	2·625	3·50	4·375	5·25	6·125	7·00
8	1·000	2·00	3·0	4·00	5·0	6·00	7·00	8·00
9	1·125	2·25	3·375	4·50	5·625	6·75	7·875	9·00
10	·125	2·5	3·75	5·00	6·25	7·5	8·75	10·00
11	1·375	2·75	4·125	5·5	6·875	8·25	9·625	11·00
12	·150	3·00	4·50	6·00	7·500	9·00	10·50	12·00
15	1·875	3·75	5·625	7·5	9·375	11·25	13·125	15·00
18	2·25	4·5	6·75	9·0	11·25	13·5	15·75	18·00
24	3·00	6·00	9·00	12·00	15·00	18·00	20·00	24·00

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No. CXXIII.

PRACTICAL NOTES ON ROADS AND CANALS.

By T. Login, Esq., C.E., *Exec. Engineer, 8th Division, Grand Trunk Road.*

In selecting a new line of road, the following suggestions may be of service in assisting the Engineer in determining what line should be adopted.

The average section of our Imperial roads in upper India may be taken at as follows:—

Breadth of top of embankment, 40 feet.

Height of embankment, 4 feet.

Slopes, 5 horizontal to 1 perpendicular.

Breadth of arches of bridges, 30 feet.

Breadth of metal, 16 feet by 9 inches thick.

Rate of earthwork, Rs. 2-8 per 1,000 cubic feet.

Rate of consolidated metal, per inch per mile, Rs. 750.

Cost of maintenance, per mile yearly, Rs. 750.

Cost of drain bridges, per running foot of water-way, from 75 to 100 Rs. up to 15 feet span.

Cost of large bridges, from 300 to 400 Rs. per foot.

The rates here given will be found a close approximation to the actual cost, only that for earthwork is rather over than under what the probable expenditure may be.

From the above data we obtain the following comparative cost of embankments, bridges and metal.

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Cost of one mile of embankment $(40 + 20) \times 4 = 240$, @ Rs. 2-8 per 1,000 = 0·60 or Rs. 0-9-7 per foot.

$\therefore$ One mile costs $5280 \times 0{\cdot}60 =$ Rs. 3,168.

The cost of drain bridges is $\frac{75 \times 100}{2} =$ Rs. 87-8 per foot.

Therefore, the cost of one mile of embankment equals only 36 feet of water-way for drain bridges, while only 10 running feet of water-way of such bridges as that over the Markunda equal the cost of one mile of embankment.

One mile of metal costs $750 \times 9 =$ Rs. 6750, or more than double the embankment; and taking the maintenance of road, at Rs. 700 a year for metal, and Rs. 50 for earthwork, at 20 years' purchase, we have for metal $700 \times 20 =$ Rs. 14,000 a mile; therefore the cost of metal is Rs. 20,750 a mile, or more than six times the cost of the embankment.

From the above, therefore, it is evident—First, that all cross drainage should be avoided where practicable, and that *the height of embankments should not be so much taken into consideration as the length of road*, so as to save metal.

Secondly, as the cost of metal is such an important item, and as this so much depends on the distance from the quarries in selecting a new line, *the proximity to kunkur beds should form a very great reason for adopting one line in preference to another.*

Supposing the wear and tear of metal to be 7,500 cubic feet a year per mile, and that 8 annas is saved for each mile the road is nearer the quarries, the actual saving would be 7,500, @ Rs. 0-8 = Rs. 37-8 a mile, which at 20 years' purchase equals Rs. 750. Thus, if 4 miles could be saved in carriage, it would equal the first cost of the embankment nearly; or the road may be lengthened one-sixth between two points without adding to its cost; that is 16·66 per cent. longer, which would admit of a diversion of about one-third of the total distance out of the straight line.

Lastly, where nothing is to be gained by deviating from the straight line, either in avoiding drainage or being nearer kunkur beds, the embankment may be raised as follows, without adding to the cost of the road, with the following rates for earthwork :—

Height of embankment up to 5 feet, Rs. 2-8 per 1000
" " above 5 and up to 10, Rs. 3 per 1000
" " 10 and up to 15, Rs. 3-8 per 1000

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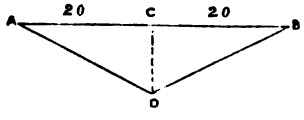
Saving in distance	1 mile in	2, or $\frac{1}{2}$,	embankment may be raised to	13·00	feet.
	1 „	„ 3, „ $\frac{1}{3}$,	„	10·00	„
	1 „	„ 4, „ $\frac{1}{4}$,	„	8·40	„
	1 „	„ 5, „ $\frac{1}{5}$,	„	7·45	„
	1 „	„ 6, „ $\frac{1}{6}$,	„	6·64	„
	1 „	„ 7, „ $\frac{1}{7}$,	„	6·10	„
	1 „	„ 8, „ $\frac{1}{8}$,	„	5·80	„
	1 „	„ 9, „ $\frac{1}{9}$,	„	5·50	„
	1 „	„ 10, „ $\frac{1}{10}$,	„	5·33	„
	1 „	„ 15, „ $\frac{1}{15}$,	„	5·00	„

That is, if the road can be shortened from $\frac{1}{20}$ to $\frac{1}{15}$ of its length, add one foot to height on an average throughout the whole length of embankment; from $\frac{1}{15}$ to $\frac{1}{9}$, add $1\frac{1}{2}$ feet; from $\frac{1}{9}$ to $\frac{1}{7}$, add 2 feet; for $\frac{1}{6}$ and $\frac{1}{5}$, add 3 feet; if $\frac{1}{4}$ is gained, add $4\frac{1}{2}$ feet; where $\frac{1}{3}$, add 6 feet; and where the distance is halved, add no less than 9 feet to the height of embankment. That is, supposing a valley to intervene, which is one mile broad and requires an embankment averaging 13 feet high to cross it, but by going a circuitous road which would avoid this bad ground, but add one mile to the length of the road (all other circumstances remaining the same along the line), it is as *cheap* to make the 13 feet embankment as to go the more circuitous route, while travellers are saved one mile. In other words, it is very seldom a road should be made to deviate from the straight line on account of earthwork only, except in a hilly country, where steep gradients would interfere.

Considerable deviations can however be made from the straight line without adding much to the actual length of road, as will be seen by the following:—Let A and B be (say) 40 miles apart, and half way, at the point C, lay off the perpendicular line CD. Suppose CD is one-tenth of AB, the line ADB will only exceed AB 2 per cent. The Engineer, therefore, at half the distance between the two points to be connected, has a breadth of 8 miles to select from, without adding more than 2 per cent. to the whole length of road. If $\frac{1}{6}$, or 16·66 per cent. be added, (the limits where the cost of embankment and maintenance of metal equal each other,) the divergence may be upwards of 13 miles on either side. Such a deviation from the straight line is much too great; so, in practice, if cross drainage can be saved to the extent of saving only 14 square miles in a distance of 40



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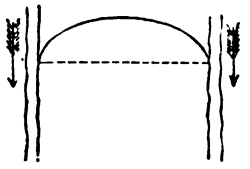
miles, it comes to the same thing as to cost, as adding 2 per cent. to the length.

Thus, Rs. 3,168, cost of one mile

$$\times \frac{\text{(2 per cent. on 40 miles} = 0{\cdot}8) \times 7 \text{ (cost of earthwork and metal)}}{87{\cdot}5 \text{ (cost of one foot of water-way)}} = 202{\cdot}7$$

and by page 135, of Vol. II. of Professional Papers, Colonel Dickens allows 42 feet of water-way for 3 square miles; but, by adding 2 per cent. to the length, we do not merely gain 14* square miles, but $\frac{40 \times 4}{2}$ = 80 square miles, where the road runs at right angles to the drainage.



Therefore, there can be no doubt that where we have a road (say) crossing from the Ganges to the Jumna (all other points being the same), that instead of it being a direct line right across, it should curve considerably upward, thus—

The extent of deviation in a distance of 40 miles, and the per centage added to the length of road is here given:—

	Miles.	Per centage		Miles.	Per centage.
1	in	40 = 0·15	11	in	40 = 12·41
2	„	40 = 0·50	12	„	40 = 14·28
3	„	40 = 1·24	13	„	40 = 16·18
4	„	40 = 2·00	14	„	40 = 18·10
5	„	40 = 3·00	15	„	40 = 20·00
6	„	40 = 4·27	16	„	40 = 22·12
7	„	40 = 5·62	17	„	40 = 24·18
8	„	40 = 7·11	18	„	40 = 25·60
9	„	40 = 8·80	19	„	40 = 27·51
10	„	40 = 11·00	20	„	40 = 29·33

From which it appears, that so long as the deviation is kept within moderate distances, the additional length is little; for even up to one-fourth of deviation of the total distance, only 11 per cent. is added; but where this is exceeded, the per centage increases fast.

Suppose the bearing between the two points to be connected is 90°, or due east and west; so long as the bearing of no part of the line does not exceed 100° or less than 80° for all practical purposes the road will be nearly as short as the direct line, while it gives the Engineer considerable scope for selecting his line. In doing which, he should consider, first,

* $\frac{202{\cdot}7 \times 3}{42}$ = 14 square miles.

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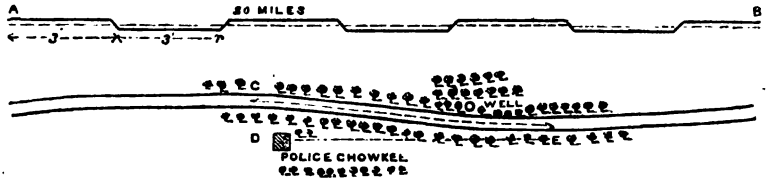
the Drainage; secondly, the supply of Metal; and lastly, the Earthwork, which, though at first sight it appears the greatest, is in reality insignificant in comparison to the other two items.

A straight line is undoubtedly the shortest distance between two points, but nothing is more monotonous than to have to march along a straight road. In fact, one should never be able to see more than three miles along any road; and this can be easily accomplished by passing round a village or a clump of trees. Curves, however, are unsightly in an open plain, unless there be some natural feature in the country necessitating a curve, such as to cross a stream at right angles, or to avoid low, marshy ground, or some high mound. In the latter case the mound can be taken advantage of in hiding the road. Where, however, all is one extensive plain, as one often meets with in India, to put a curve in a road and not to *hide* it, appears as if a mistake had been made in lining it out, which is worse than a continuous long line.

Curves may however be given at every three miles, so that no portion of the road can be seen for a greater distance, and the road greatly improved, not only in appearance, but also in comfort to travellers. Suppose the distance between the two points it is necessary to connect is 30 miles apart, and that the country is one open uniform plain. The shortest line would no doubt be one uniform straight, but it would be too tedious, and would involve long marches of 15 miles each, with nothing to break the monotony of the march. By introducing Ogee or S curves at every three miles, and planting two clumps of trees near them on either side of the road, with a well in the centre of one of them, the road could only be seen along three miles of its length, and wearied travellers would have comfortable shade with water to drink. A Police Chowkie could be placed in the other clump, so as to afford protection to property.



Supposing DE to be equal to 1000 feet, and CD equal 50 feet, then $\sqrt{1000^2 + 50^2} = 1001{\cdot}24$ feet; or nine of these curves may be introduced

and only add to the length of the road in a distance of 30 miles, some four yards. In practice, therefore, the distances become one and the same, and as to lining out, the Engineer need only mark out the straight dotted line and level along it, leaving the classies to mark out the offsets and lay out the Ogee curves with a chain and graduated set square, which any intelligent man could be taught how to do in a few hours. This is done by setting off at, say every 100 feet, at right angles, any distance the Engineer considers necessary, and then placing banderoles on the two last pegs, when 100 feet more is measured in the line of the banderoles and another offset fixed, and so on. This plan is to be found described in most engineering works on laying out roads, railways, &c., and calculations are given to find the radius of the circle described with given offsets, &c., &c.; but it is not the intention of this paper to give mathematical details, but simply practical suggestions.

In practice, therefore, it will be found most convenient to lay off the curves, not in circles, but by polygons; that is, supposing the first offset be 1½ inches, the second would be 3 inches, the third 6 inches, next 9 inches, then 1 foot, 15 inches, and so on. When the centre of the desired curve is reached, the offsets to decrease in a similar manner. By introducing one length of chain in a straight line after the last offset of the curve, the second portion of the Ogee can be marked off in a similar manner; thus a set of curves can be laid down on the ground by an intelligent classie in less time than it would take to survey and calculate out the proper offsets.

The curves, also, having more the character of parabolas, that is, commencing flat and ending in the same manner, while the centre is sharp, look well on a road, and by many have been considered better for railways and canals. With the railway there is no quick change of the course, which sometimes causes the engine to run off the line. With canals such a curve is better than an arc of a circle, as it causes less sudden derangement of the flow of the water; for it is evident that the tendency of water is to deepen the bed where the velocity is greatest; that is, along the extrados; thus there will be a much greater body of water passing down on the one side than the other. Consequently the water will naturally take to the line of least resistance on leaving the curve, and instead of flowing down in the direct line of a canal, will attack the opposite bank.

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In marking out roads through the plains of India, for all practical purposes, if the levels are known at every 400 feet, a sufficiently close approximation to accuracy will be arrived at to calculate and estimate the earthwork. At each of these pegs, 400 feet apart, a bamboo should be driven to the required height, and on this bamboo should be marked the height* and number of the peg according to the section. Also much time is saved by cutting on the ground at a little distance from the line the number of each fifth station in large figures.

The barrow pits or tanks from which the earth for the embankment is obtained, should also be uniform in size, say 150 feet long with a space of 50 feet intervening. This enables the Engineer to check the measurements at any time, and prevents a flow of water parallel to the road, while it stores up water in the rains that can be used for consolidating the embankments, a matter of great importance in the future maintenance of the road. These tanks should not only be uniform in length, but also of given breadths—advancing by 5 feet at a time—such as 20, 25, 30, 35, and 40 feet broad, according to the quantity of earth required. By this means there is no necessity for measuring the length or breadth, for the eye can at once detect any error; so only the depths are required to be taken, and by having the contents readily calculated out in a tabular form in one's note-book, the content and cost of each tank is known at a glance.

In practice, after the height of embankments is fixed at every 100 feet along the centre line, an intelligent classie with a good eye and an optical square can mark out the slopes and tanks, and the whole can be done for less than 10 rupees a mile, that so the Engineer's time need not be taken up with such details when once he has seen the work properly started.

By this arrangement also, the breadth of land required to be taken up is at once settled, and as it consists of long parallel strips, all disputes about areas and boundaries are avoided, while the work of the Civil Officers is much reduced. Much time and money would be saved, and much more satisfaction would be given to the zemindars, if the Executive Engineer were permitted to walk up the line and pay the villagers on the spot the compensation for whatever trees, crops, &c., there may be on the line, taking receipts for the same. He should always give Rs. 25 per cent. over the market value of what is destroyed. If the

* Allow 1 foot for sinking in every 7 feet of height.

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loss of time and the pay of Civil Officers' Subordinates be taken into consideration, the cost to Government far exceeds Rs. 25 per cent., while the villagers are better satisfied by getting ready money. If the Executive Engineer cannot be entrusted with paying such compensation, neither should he be trusted with paying his workmen.

In conclusion, it may be stated that portions of our Grand Trunk Road are now actually costing more to keep in repair than a line of railway; the latter being about 100 rupees a month a mile, while portions of the Grand Trunk Road are costing upwards of 120 rupees a month a mile. With such an enormous expenditure, therefore, increasing year after year, a time must be soon reached when all the available money will be swallowed up in repairs, unless more funds be supplied by local taxation, or some other means be devised for the traffic, which is daily increasing.

The only way therefore that appears to meet the difficulty is to have Navigable Canals. The chief cost of these works will be the first outlay; but after that, the maintenance will be, comparatively speaking, little beyond the loss of a little water by evaporation and absorption; but as the velocity will be slight, the bed can be puddled, and thus the leakage reduced to a minimum.

Supposing that the loss of water by absorption and evaporation, including lockage at the lower extremity of a canal, is in all $1\frac{1}{2}$ feet a second per mile, and that it will require 500 miles of navigable canal to connect Roorkee, Saharunpore, Kurnal and Delhi with Allahabad. Also that 100 yards average breadth of land is required for the canals, and that an acre of land is worth Rs. 40, while a cubic foot of water per second is worth Rs. 400 a year.

We have $500 \times 1\frac{1}{2} \times 400 =$ Rs. 3,00,000, and one square mile of land required for every 17·6 miles of canal or $\frac{500}{17 \cdot 6} = 28$ square miles. Then $\frac{28 \times 640 \text{ acres} \times 40 \text{ rupees}}{20 \text{ years' purchase}} =$ Rs. 36,360; or in rough numbers, the expenditure on land and water would equal Rs. 3,50,000, or about the present expenditure on two divisions of the Grand Trunk Road; independent of the expenditure from the local funds on the maintenance of roads. Now, if the navigable canals would relieve the roads of one half of the traffic, it appears that were water communication adopted, the saving of wear and tear on the Imperial roads alone would almost cover the compensation for land and loss of water. Therefore, if Government gave the

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land and the water for nothing to a private company; with the *present traffic*, Government would be no loser.

These canals should run through the centres of the chief cities, and the full 100 yards in width should be taken up, the company paying the compensation for all buildings, &c. This, though a great outlay at first, would ultimately pay well; for supposing 100 feet to be required for the canal, 100 feet for roads 50 feet broad on either side; there would still remain 50 feet also for building sites, the rents for which would fully pay for the compensation.

The surface level of the water should be at least 1 foot above the roads, so that there could be no drainage into the canal, and there would be always a flow of clean water through our chief cities. With an open space 200 feet wide through every town, a flow of clean water, with the merchandize brought up to the door of every shop-keeper, not to speak of the water power available at every lock, it is difficult to imagine how much the country would be benefited without putting Government to any extra expense, while the projectors of such works would find it highly remunerative.

Judging from Major Crofton's estimates, the probable cost per mile for a 50 feet broad navigable canal should not exceed Rs. 20,000

To this add compensation, management, &c., 10,000

Total, 30,000

or 500 miles of navigable canals may be constructed through the richest portion of India to connect its chief cities, at a cost of not more than one and a half million pounds sterling.

Taking the average slope of the Doab at 17 inches in the mile, and that of the canal only 6 inches, 11 inches have to be got over by locks in every mile, or in all say 450 feet and taking the discharge at 250 cubic feet a second passing through these locks, we have (*see* Beardmore's Hydraulics) water power per foot of fall as follows:—

	Horse power.
Undershot wheel, ...	9·9 × 450 = 4,455
Breast „	15·6 × 450 = 7,020
Turbine „	21·3 × 450 = 9,585

Or an average of 7,020 horse power.

Supposing only one-half of the power be made use of, we have distributed over the country 3500 horse-power, available for sugar, oil and grain mills, &c., &c.; and taking each horse-power at the low rate of 8 annas in the

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24 hours, we have at once a return of 4 per cent. on the total outlay from this source alone, independent of navigation. Now, as it is found that it is better to run the risk of rafting down sál timber from the forests at the foot of the hills on the left bank of the Ganges to Cawnpore, and then to pull it up against the stream of the Ganges canal to near Meerut, than to cart it by the direct road, some slight idea may be formed without going into figures of the difference of cost between land and water transport.*

RETURN SHOWING COST OF TRANSPORT OF 100 MAUNDS. WEIGHT OF GOODS ONE MILE.

Mode of transport.	Rate. Rs.	A.	P.	Probable distance travelled daily.	REMARKS.
				Miles.	1 md. = 80 lbs.
Ocean long voyages, ...	0	0	2·20	150	
American lakes, ...	0	0	4·76	...	
Hudson river,...	0	0	4·00	...	Obtained from
Erie canals, ...	0	0	6·35	...	report of State
Ordinary canals, ...	0	0	8·00	...	Engineer of New
Coal railways, ...	0	0	11·11	80	York for 1853.
Favorable passenger lines, ...	0	1	8·00	150	
Passenger lines, steep gradients,...	0	2	8·25	150	
East India Railway, lowest rate,...	0	2	1·00	150	
Country carts, over metalled road,	0	4	0	12	Indian rates
" " country "	0	5	4·00	12	of transport for
Indian Carrying Company over the Grand Trunk Road, ...	0	6	11·00	33⅓	grains and the cheapest description of goods.
Probable rate by Navigable Canals in Upper India, ...	0	1	0	12	

NOTE.—The probable rate of interest to be charged on goods would be one anna per 100 rupees daily, or 22½ per cent. nearly (22·8 per cent.) Therefore the cost of transport of 100 maunds of grain, worth 100 rupees at prime cost, conveyed by Canals a distance of 300 miles, would be—

	R.	A.	P.
Cost of carriage of 100 maunds $\frac{300}{16}$ ... ... =	18	12	0
Time of transport, 25 days, at Rs. 0-1-0, ... =	1	9	0
Total, ...	20	5	0

or nearly 20 per cent. on prime cost.

* The charge for the conveyance of goods by the Inland Transit Company along the Grand Trunk Road for a distance of less than 80 miles, is greater than the freight from London to Calcutta.

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	R.	A.	P.
Should the rate be reduced to 8 pie a mile,			
The cost of carriage of 100 mds. $= \frac{300 \times 8}{12 \times 16}$ =	12	8	0
Time of transport, 25 days, at Rs. 0-1-0, ... =	1	9	0
Total, ...	14	1	0

or only 14 per cent. on prime cost.

	R.	A.	P.
By the lowest rate of Railway charges,			
The cost would be 300, at Rs. 0-2-1, ... =	39	1	0
Add time of transport, 2 days, ... =	0	2	0
Total, ...	39	3	0

or 39 per cent. on prime cost.

	R.	A.	P.
By country Carts on Metalled Roads,			
The cost would be 300, at Rs. 0-4-0, ... =	75	0	0
Add time of transport, 25 days, ... =	1	9	0
Total, ...	76	9	0

or 76·72 per cent. on prime cost.

	R.	A.	P.
By country Carts on Unmetalled Roads,			
The cost would be 300, at Rs. 0-5-4, ... =	100	0	0
Add time of transport, 25 days, ... =	1	9	0
Total, ...	101	9	0

or over cent. per cent. on prime cost, with no allowance made for back hire.

	R.	A.	P.
By Bullock Train over the Grand Trunk Road,			
The cost would be 300, at Rs. 0-6-11, ... =	114	3	6
Add time for transport, 9 days, at Rs. 0-1-0, ... =	0	9	0
Total, ...	114	12	6

or nearly 115 per cent. over prime cost for the cheapest class of goods, and 100 per cent. over the lowest rate by canals.

Comparing the cost by Railway and by Canal, if the canal rate is one anna a mile, it is only one-half the railway rate nearly, and about one-third the railway rate if the charge be only 8 pie. Therefore, till the interest on the capital of prime cost makes up the difference owing to the loss of time by the canal, water transport would be preferred to railway carriage. That is, no goods would be sent by railway under ordinary circumstances that cost less than 14 rupees a maund, for

	R.	A.	P.
100 maunds transported 300 miles, @ Rs. 0-1-0, .. =	18	12	0
Interest on 100 maunds, @ Rs. 14 for 25 days, @ Rs. 0-1-0 per cent., ... =	21	14	0
	40	10	0

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And 100 maunds for 300 miles, @ Rs. 0-2-1, ... =	39	1	0
Interest on 100 maunds, @ Rs. 14 for 2 days, @ Rs. 0-1-0 per cent., ... =	1	12	0
	40	13	0

Again, suppose one European Soldier costs the state £100 a year, or Rs. 2-11-10 daily, and that he can be conveyed by rail 1,000 miles for Rs 16 in three days, the cost to Government would be—

	R.	A.	P.
Rs. 2-11-10 × 3 .. .. =	8	3	6
Add railway charge, ...	16	0	0
Total, ..	24	3	6

To march 1,000 miles at the rate of 12 miles a day, without halts, would occupy 83 days, and Rs. 2-11-10 × 83 = Rs. 227-6-4 ; or by a quick railway he can be carried at nearly one-tenth the cost to Government than if he had to march, and his services are available 80 days sooner. The natural conclusion to be arrived at therefore is, that both quick Railways and slow navigable Canals, are required for the protection and development of India.

T. L.

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No. CXXIV.

KANWAR HARBOUR WORKS.

Report by CAPTAIN W. GOODFELLOW, R.E.

A REFERENCE to the accompanying sketch will show that the Bay of Kanwar is sheltered from gales from the south-west, the great desideratum of harbours on the western coast of the Indian Peninsula.

A Harbour Engineer of experience was deputed in the year 1858, for the purpose of examining and reporting on the capabilities of Sedashewghur, with reference to the formation of a harbour of refuge, and he recorded the following opinion:—

"The bay is at present partially protected from the monsoon, during the time of its greatest violence, in the months of May and June, when the direction of wind is nearly south-west, but it is exposed to the west and north-west. It might be sheltered from these quarters by the construction of breakwaters of altogether about a mile and a half in length, and a perfectly quiet harbour thus formed of upwards of four square miles in area, with a depth varying from 14 to 32 feet at low water, and thus capable of accommodating, at all times of the tide, the largest descriptions of merchant ships, and all but the largest of the Royal or Indian Navy. The bottom is remarkably even, and consists of a stiff mud.*

"The facilities for the formation of these works, should they ever be contemplated, are very great, Kanwar Head consisting of granite of the very best quality. As a harbour of refuge or naval station, Sedashewghur, thus protected, would be quite equal to the fine harbours now in course of construction at Dover, Portland, Holyhead and Alderney, and I think at a less expense, compared with the accomodation afforded, than any of these.

"Although the Government may have no intention of immediately

* This is not the case; it is bad holding ground.

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availing itself of the facilities here presented, I think it right that they should be brought to the notice of His Lordship, and that in any disposition of the neighbouring land, or in the formation of any works for the improvement of the navigation for the benefit of trade, regard should be had to the possible future requirements of a large national undertaking."

"There* is now no port (in the British territory) on the western coast of India, south of Bombay; for the bar at Cochin prevents any but very small vessels from entering it. It is evident that if a good port were made at Sedashewghur, the produce of North Canara, Dharwar, Belgaum, Bellary, the Raichore Doab, and some of the northern Districts of Mysore, would be exported from it, and a great import trade would also be attracted to it. In a naval, military, and political point of view, the advantages of a port on this part of the coast can hardly be over-rated."

"Even† in its unimproved state, the bay of Sedashewghur appears to possess to a certain extent the advantages of a natural harbour; these are such that even now it is capable of affording secure anchorage to a small number of large vessels, and there is nothing to prevent the use of the port as it stands at present as a harbour for trade, but the want of trade. To‡ create such trade it is only necessary to open a communication between the port and the productive country above the Ghauts, from which it is now cut off."

I have inserted the foregoing recorded observations as leading up to the decision relative to works to be undertaken; for the bay having been selected as a harbour, it was decided that the works necessary to make a port should be carried out, and at a cost not far in excess of that which the amount of shipping likely to frequent the harbour would justify.

It is proposed that at first only such works should be undertaken, as may be absolutely necessary to meet the requirements of the locality, more particularly in regard to supplying greater facilities of export for the cotton of Dharwar and the adjoining districts.

It will be admitted that a—Light-house—Wharf—Pier—Wells for Water Supply, and a Wharf Road to connect roads approaching the port, and afford access to the pier, are all works indispensably necessary for the opening of the port; and such only are embraced in this report, or pro-

* Extract minutes, dated 27th April, 1858, by Lord Elphinstone.
† Lord Stanley, P. W. Despatch to Government of Madras, 6th October, 1858.
‡ P. W. letter, from Government of Madras, 16th May, 1860.

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KANWAR HARBOUR WORKS.

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vided for under the term "harbour works" in the accompanying plans and estimates.

Light-house.—The position the light-house should occupy was decided on the principle which advocates the necessity for lighting dangers at the entrance of a harbour, rather than lighting the passage into the port and to the anchoring ground. I here quote from documents bearing on this subject:—

"With reference to the light-house,* we were inclined to prefer placing it on Kanwar Head rather than on the Oyster Rocks, as advised by the Marine Board, but thought that if the harbour were formed, it might be advisable to have one on each locality."

"The only portion of the scheme† which calls for immediate consideration is that relating to the exhibition of lights, which are recommended both on the Kanwar Head and one on the Oyster Rocks, which lie in a westerly direction from the shore, and one more to seaward than the site proposed for the light-house. The near proximity of these positions to each other (the intervening distance being about three miles only) would, it appears to us, make it unnecessary to build more than one light-house off Sedashewghur.

"Lieutenant Taylor recommends that a light-house should be built on Kanwar Head, which is 640 feet high, whilst the Marine Board, following Capt. Biden, advise its being built on the largest of the Oyster Rocks, with a beacon or obelisk on Kanwar Head.

"Captain Biden remarks:—The outer or western Oyster Rock offers a better site for the erection of a light-house than Kanwar Head, as that position is upwards of three miles to seaward, and in thick weather, the discovery of a light indicating the approach to danger, so much further to windward, would be a great advantage.

"The Oyster Rock is 160 feet above the level of the sea, which is a sufficient elevation for the display of a light. We presume that whether a harbour of refuge at Beitkul cove shall be determined upon or not, a good light in that neighbourhood would be very useful to the shipping in general navigating the coast, and not merely for the vessels expected to frequent the projected harbour. In this view of the subject it seems to us

* Extract Letter from Government of Madras to Court of Directors, No. 22, of 7th October, 1856.

† Extract Despatch in Marine Department, from Court of Directors to Government of Madras, No. 15 of 18th May, 1858.

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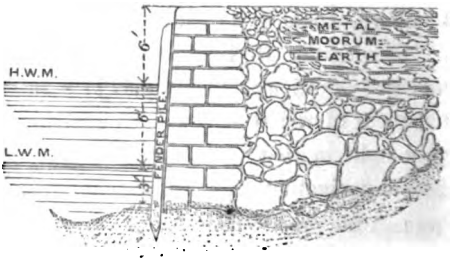
that the dangers most to seaward ought to be specially guarded against. We therefore approve of the western outer Oyster Rock as the most eligible site for the intended light-house. When the harbour of refuge shall have been constructed, a smaller light to guide vessels to the anchorage may be added in the position best suited for that purpose."

In March 1862, the precise spot for the light-house was fixed by the Chief Engineer and Secretary to Government Public Works Department, and the works ordered to be commenced.

The light will be shown from the summit of a tower 40 feet high, to be erected on the largest of the Oyster Rocks, which are three and a quarter miles from the main land; the total elevation of the light above the sea will be 200 feet. The Oyster Rocks are composed of large disrupted masses of granite; and this stone will be used in the construction of the column; the skilled labor necessary for the construction of such a column will have to be imported; no stone masons, or indeed artificers of any kind, being procurable in Canara.

The light-house will consist of a hollow column, interior diameter 10 feet, with a batter of 1 in 12 on the outside; wooden staircases, with three boarded landings inside. The necessity for great *strength* and durability has alone been considered in the selection of the design and nature of construction. The lantern ordered from England is to be one of the first order, 29 feet high from floor of lamp-room to vane, and will show a light for a complete circle.

Wharf.—The sight selected as likely to prove most convenient for the wharf is on the east of Beitkul cove. The adjacent hills come down to the water's edge rather abruptly, and the shore between Beitkul and Koney, with the exception of the sandy beach in front of Allygud-day, and at the head of Beitkul cove, is composed of rough slopes of granite and boulders embedded in gravel and clay.



The manner in which the wharf walls are to be constructed is shown in the sketch, and may be described as follows:—

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The rocky hill side to be blasted away; large blocks of stone coming from the hill to be roughly dressed and carefully laid, but without mortar, to form the wall, the foot of which will be 3 feet below low water-mark. The wall to be 4 feet thick at top, and built with a batter of 1 inch to a foot in the face, and with vertical back; being filled in behind up to nearly high-water mark, with dry rubble, hand packed, and above that with earth, or whatever material may come from the hill side immediately in rear. The authority for the above description of wall may be traced in the extract from a joint report by Colonel Turner, R.E., and Mr. Hope, B.C.S., given below.

"Having ascertained that there is no hard foundation in many parts of the cove, even at a depth of 14 feet, the construction of any solid masonry work would involve expensive coffer-dams, means of unwatering them, &c.; we have therefore directed that on the line BC, shown in the plan, a dry stone wharf wall be built in the sand in about 3 feet at low tide. This will probably settle, and it is possible portions of it may have to be rebuilt, but even then its cost will be trifling compared with a wall of masonry founded on the rocks, and the shell-fish in the cove will soon unite the stones."

The wall has stood well, and the shell-fish have almost closed the openings in the joints of the lower half of the wall.

The estimates now submitted provide only for wharf accommodation to the extent of nine acres on the eastern side of Beitkul cove and in rear of the pier.

Pier.—The description of pier considered most suitable, and adopted, is that consisting of a strong wooden platform, supported on wrought-iron screw piles, 6 inches in diameter and placed 10 feet apart, so as not to interfere with currents along the shore, and to prevent silt being deposited, or the scouring of any portion of the existing bed of sand and shells, which might endanger the stability of the wharf walling.

The position the pier should occupy (*see* sketch) has been decided by Government with reference to two important considerations, viz., the point likely to be most convenient for public use in the shipping and landing of goods, also where there is smooth water during rough weather, and a sufficient depth of water to admit of the largest cargo boats being loaded and unloaded at all stages of the tide.

When the wharf walls approaching from the Beitkul and Allygud-

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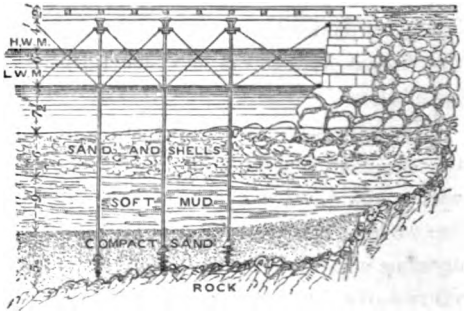
day directions meet, it is proposed to construct a suitable abutment (of heavy blocks of granite dressed and laid without mortar, founded on a base of "pierre perdue" work) to receive the shore end of the screw pile.

The sketch given below represents a section through pier abutment, and shows the position of the first rows of piles, and the depth to which the same will have to be screwed.



It was at first intended to construct a pier 200 feet in length, with a T head of 90 feet in length, both portions having a uniform width of 30 feet; and the contract for this work was taken up by Mr. George Wells, of North-Street, Westminister; the sum stipulated to be paid for the iron-work being £7,476. The contract was made by order of the Secretary of State in Council, and signed in London on the 7th August, 1863; time allowed for completion of the work being ten months from date of signing the articles of agreement.

The iron-work was examined and tested in England, shipped at Newcastle, and despatched on the 29th November, 1863; but the ship did not arrive at Kanwar till 7th June, 1864; by the 16th of July all the cargo was discharged, and everything got ready to proceed with the pier work.

I must not here omit to mention that, though the cargo was discharged during June and July, there was no difficulty or delay. The ship (600 tons burthen) was moored at the mouth of the Beitkul cove, and about 80 yards from the wharf; the wrought-iron piles, 36 feet long and 6 inches in diameter, were delivered into a lighter out of the bow ports of the vessel, which were scarcely a foot out of the water. This fact speaks for itself, and may be received as early record of the capabilities of this natural harbour, as a place of refuge from all that is to be dreaded during the south-west monsoon. After a few rows of piles had been screwed down, it became apparent that owing to the peculiarly treacherous character of the beds of sand and mud, it would be necessary, in order to

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secure perfect stability, to screw the piles to a very great depth, greater indeed than is usual for such structures; under these circumstances, and considering that if the pier were shortened, there would be only 7½ feet of water, instead of 9 at low water spring tides, in front of the pier, it was decided to convert the pier into a landing stage about 100 feet square, and make use of the materials for this purpose—running out the landing stage in the same direction as the intended pier, and mounting the cranes in the positions it was originally intended they should occupy.

The landing stage was completed on the 23rd November, 1864, and cannot fail to prove most useful; for the largest cargo boats built may be alongside at all stages of the tide, and heavy bulky goods will only have to be moved 100 feet from the wharf, instead of 230, to be brought under the cranes.

The first shipment of pressed cotton, 3000 bales, for England direct, is now being made (20th December, 1864), and the wharf and pier were ready just before required by the mercantile community.

Wells, Water Supply.—The village of Beitkul is on the isthmus between Kanwar Head and the hilly mainland; on the north and south there is the sea. The surface of the isthmus is quite flat, and but little above high-water mark; it is covered with sand to a depth of 4 feet, below this there is yellow clay, and then a bed of laterite. At present water is obtained from rudely excavated wells and pits, which however, are very shallow; for it has been ascertained that if the laterite be pierced the water becomes brackish; the supply afforded by the above-mentioned wells is insufficient even for the wants of the village, and it would not be advisable to increase the supply by adding to the number of wells of the description now existing. The ground in the neighbourhood of the wharf has therefore been carefully examined, with a view to determining sites for deep wells which would yield a plentiful supply of pure water.

The hills on the east and west of the cove rise to a considerable height, and at the spots indicated on the plan, springs had been discovered; on the western side of the cove the small well which already exists can only be built up, as it would not be advisable to deepen it for fear of piercing a porous stratum, which, so close to the sea, might result in the water becoming brackish; but on the eastern side of the cove, almost on the wharf, a good spring has been discovered on the hill side, and the well to tap it thoroughly might be at least 50 feet deep, and would have to be blasted

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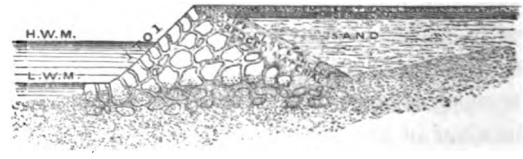
out of the rock: this well, though expensive, would prove invaluable for the wharf, and it is therefore proposed to make it 20 feet in diameter with a trough for watering cattle.

The wharf road, may be said to extend from Beitkul to Konay, commencing at a point near the head of Beitkul cove, where the road to the Arbyle Ghaut leaves Kanwar, and terminating a few hundred yards to the north of the Konay Creek, where the Kygah Ghaut enters Kanwar. The wharf road is in a hill side cutting the whole way, and a vast amount of rock must be removed except where it passes along the beach at Allegudday. There is only one stream or rather creek to be bridged (viz., the Konay nullah), but several well built drains will be required to convey the water, which, during heavy rain, rushes with violence from the steep hill sides above the proposed road.

The wharf road is to be 100 feet wide, and formed as shown in sketch below; material from the excavated portion of the hill which is not retained by the wharf wall, being protected from the wash of the sea by a stone bank, having a slope on the sea face of 1 to 1.

The surface of the wharf wall will be 6 feet above ordinary high-water mark, and the surface of the road will gradually fall away to 4 feet above high-water mark, which will be the average height of the top of the stone bank retaining the road; except for the portion between Allegudday and Konay, where, owing to the amount of rock that would have to be cut away to keep the road level, the surface rises at an easy gradient towards a ridge cutting, and then falls again towards Konay, where the road surface is only 4 feet above high-water mark. For bridging the Konay nullah in a suitable manner, an iron lattice girder bridge has been adopted; it consists of two spans, 40 feet each, supported on hollow cast-iron screw piles, carrying a roadway 40 feet wide.



The iron bridge was erected in preference to one of masonry, owing to the difficulty of obtaining foundations, and the necessity for economizing masonry supports such as piers.

The estimated probable cost of carrying out the works above briefly described, is as under:—

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		Rs.
No. 1.	Estimate for light-house (exclusive of expenditure in England for lantern), ...	41,451
„ 2.	„ wharf wall, ...	307,390
„ 3.	„ pier, ...	77,661
„ 4.	„ wells, ...	4,801
„ 5.	„ wharf road, including iron bridge, ..	655,668
„ 6.	„ steamer charges, ...	45,565
„ 7.	Miscellaneous expenditure, ...	18,600
	Grand Total probable cost of Kanwar Harbour works, ...	1,151,136

W. G.

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No. CXXV.

WATER-WAY OF THE SYE BRIDGE.

Report by LIEUT.-COLONEL C. W. HUTCHINSON, *Officiating Chief Engineer, Oudh.*

BEFORE passing the Estimate for the Sye River Bridge, on the Allahabad and Fyzabad Road, submitted on the 12th April last, Government of India remark, that the drainage area of the Sye, as deduced from the maps of Oudh, would seem to require three times the amount of water-way provided for in the project, and desire that I should submit a report to clear up this point.

This question was carefully considered when the estimate was under preparation, and the discrepancy above-mentioned was noticed, and calculations were made to show that by using Colonel Dickens' Formula for Flood Discharge of Rivers, and calculating the area of the catchment basin as it appeared on the maps of the province, the water-way necessary for a bridge over the Sye river would be fully three times that fixed by the ordinary calculations of sections and flood levels at site.

These latter however appeared to be so carefully and so certainly established; the views of the present and past Executive Engineers who had studied the subject did not differ to a great extent as regards water-way and discharge area; the site had been visited by me in October last, the features of the river had been examined, and the (probable) size of the bridge required at the site had been estimated by me, and found to agree with the dimensions fixed by the calculations as submitted to Government; the opportunities had been so good of year after year watching the volume of the river as it flowed past the ends of the new road em-

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bankments, and as it flowed under (and eventually over) a wooden bridge, which stood at the site for four years; in fact the conditions of the river at *site* of the proposed bridge seemed to have been ascertained and established so surely, that I considered that the results based on them could safely be accepted, although they were not borne out by the, as it were "check," calculations, based on the formula for volume of discharge as dependent on rainfall over the catchment basin. In sending up the project in the first instance, I might have mentioned that these calculations as to drainage area had been made, but I did not consider this necessary; the calculations had been made more for my own satisfaction than anything else, and the data not being reliable, I rejected them.

One great uncertainty in the mode of calculation by drainage area of this river was at once apparent, and prevented any reliance on the results thus obtained. The existing maps of Oudh are most incomplete as regards the course of the streams: the country in Southern Oudh is very flat, the streams generally very winding and very irregular; the waters of many streams seem during rain floods to coalesce, and the demarcation of separate catchment basins for separate streams would seem a difficult problem. It would appear from the maps, that at several points in its course, the Sye river during high floods fails to carry on, in its own channel, the waters which might be considered to pertain to its own drainage area; jheels and streams lying right and left of its course probably receiving and carrying off much of its surplus water into other adjacent lines of drainage, whose watersheds are scarcely defined. In the Oonao district, near the town of Ooras, it may be said that the flood waters of the Sye above that point are carried off in the bed of Nusseeroodeen Hyder's canal, and poured into the Goomtee below Lucknow city.

The question having been referred by the Government for further consideration, the Executive Engineer, 3rd Oudh Road Division, was directed to examine again most carefully his levels, flood marks, &c., and verify all the data furnished by them: and this he has done, and reports that all his measurements, &c., are perfectly correct. Thus the data of sections and flood marks at site stand on a yet surer basis.

It being out of the question that a survey of the whole catchment basin of the Sye river above Pertabghur could be undertaken, I determined to test the applicability of formulæ based on measurement of catchment basin, as shown by the bridges now spanning the Sye at other points;

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although these bridges have not been long constructed, they have stood at all events the test of one or two rainy seasons, and the comparison here made seems to show that other Engineers have come to similar conclusions regarding the water-way of this river; that is, they have not been guided by calculations based on the apparent drainage area.

The railway crosses, near Bunnee, the Sye and its affluent the Lonee. Considering that the drainage of the basin of the Sye above Ooras is disposed of by the canal, one may assume that when the river passes under the railway bridge, it has drained a basin 30 miles in length and about 8 miles wide, or 240 square miles. Its velocity may be taken at 5 feet as a maximum, and it is carried under a bridge offering to it only 1,280 superficial feet of water-way. This bridge, however, if cut out to the full rectangular section, could offer $24 \times 20 \times 5 = 2{,}400$ superficial feet. To guard against under estimating its capacity, assume the last named figure. This with a velocity of 5 feet would give 12,000 cubic feet of flood discharge.

Now to compare this with the flood discharge due to its basin,

$$D = M^{\frac{4}{5}} \times 825; \text{ where } M = 240 \text{ square miles.}$$

$$\begin{aligned} \log. M &= 2{\cdot}380211 \\ &\quad 3 \\ &\overline{\quad\quad} \\ &4)7{\cdot}140633 \\ &\overline{\quad\quad} \\ &1{\cdot}785158 \\ \log. 825 &= 2{\cdot}916454 \\ &\overline{\quad\quad} \\ &4{\cdot}701612 = \log. 50300 \end{aligned}$$

Here the discharge due to the catchment basin (even ignoring all drainage above Ooras) is more than four times the maximum capacity of the bridge.

Again, take the affluent stream, the Lonee, over which is thrown a railway bridge of 920 superficial feet, and if 5 feet be also assumed as its velocity, the volume of discharge equals $5 \times 920 = 4{,}600$. From the map it would seem that this stream had a catchment basin of about $20 \times 6 = 120$ miles.

Again applying the formula—M being equal to 120, we get D = 29910.

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This is more than six times the capacity of the bridge. In each case it seems that the drainage area must be much less than what the map appears to show; or that, if the catchment basin be correctly shown and measured, the watersheds are so ill defined and irregular, that it cannot be exactly ascertained in what manner the drainage apparently due to any basin is disposed of: some of it escaping laterally into other basins which may be said to coalesce with it; or the soil of Oudh is with difficulty saturated, and the whole rain-fall cannot be held at any time, even after the hardest falls, to be poured off into drainage channels.

Rankine gives as the proportion of the amount of rain-fall carried off by streams to the total rain-fall, in a *flat cultivated* country, as ·5 or ·4, and Burnell shows that the discharge of the rain-fall from different soils is very different, granite pouring off all at once, gravel absorbing nearly all. The Oudh soil might be held to be about equally porous with oolites and gravels, off which he estimates the maximum flow as one-third or ·3 only.

The comparison between the actual water-way and that found by (this) theory may be once more tested.

At Roy Bareilly the Sye river is spanned by a bridge (designed by a Civil Engineer formerly in this Province) of 5 spans, each 22 × 30, or 3,300 superficial feet of water-way, or 5 × 3,300 = 16,500 cubic feet. Let this be compared with the flood discharge due (apparently) to the drainage area. This is the sum of the area above found (360) and a further course of 40 × 15, about = 600, or 960 in all.

By the formula we then get D = 142300. This is *eight* times the capacity of the bridge.

Even if the Sye (a winding slow river, of which the velocity is rather under 5 feet) be supposed to rush with a velocity of 10 feet through the Roy Bareilly bridge, the capacity of that bridge is still less than four times that due *apparently* to its drainage area.

These instances are simply given, as already said, to show that other Engineers have provided in bridges over this river less water-way in proportion to the supposed drainage area than that provided in the project submitted from this office in April last—whether they have provided sufficient water-way or not, I am not prepared to say, but I think that to adopt the formula above used to the Sye river, it will be safe to divide by 3 (at least), the result found by computing its *apparent* catchment basin from the maps now extant of this province. And this result is borne out in

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the case of the proposed bridge near Pertabghur, by that deduced from the data and observations mentioned in the beginning of this memo.

Although the question has but an indirect bearing on the point at issue, viz., the applicability of calculations based on apparent drainage area to the flood discharge of the Sye nullah, yet it will be interesting to show the results of such calculations on other neighbouring Oudh rivers, whose conditions have been more exactly determined.

The "iron bridge" over the Goomtee, at Lucknow, has stood for 20 years, and extraordinary floods have passed off safely under it. This bridge has a water-way of 4,142 superficial feet. Careful levels have been taken of the bed of the river from one mile above to one mile below, and the *natural* mean section of water-way has been found to be 8,277 superficial feet, with a natural velocity of 2·6, or a flood discharge of 21,520 cubic feet. The increased velocity due to the contraction of water-way under bridge is 5·4, and the flood discharge calculated from this velocity and the water-way of the bridge is 22,366 cubic feet. Let this greater volume be assumed as the actual flood discharge of the Goomtee at Lucknow, when it has had a course of 133 miles and drained a basin (apparently on an average) 20 miles in width. In order not to over estimate its drainage area let it be calculated as 133×15 feet $= 1,995$; say 2,000 square miles.

Then by the formula—we get $D = 246780$ cubic feet.

This is more than ten times the actual maximum discharge, and would require a velocity of nearly 69 feet per second to carry it through the iron bridge, and yet it is believed that the area of the catchment basin (as it would appear to be defined on the maps) is rather under than over estimated.

Again, over this same river (the Goomtee) at Sultanpore, a pile timber bridge has stood for many years, having a water-way of 5,200 square feet. Between Lucknow and Sultanpore the Goomtee drains a basin from 20 to 30 miles wide, with a length of a little over 80 miles; $20 \times 80 = 1,600$ square miles, is certainly under the area of this portion of the Goomtee catchment basin, but will be assumed in calculation. Thus the drainage area above Sultanpore is not less than

$$2000 + 1600 = 3600 \text{ square miles ; whence } D = 3,83,420.$$

To carry this volume through the Sultanpore bridge would require a velocity of 73 feet per second; and, consequently, the flood discharge as above deduced is fully ten times larger than it really is.

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One more example may be given of an Oudh stream, whose flood discharge during the remarkable flood of September, 1863, has been well ascertained. This stream is the Kullianee, which crosses the Lucknow and Fyzabad road, and its branch to Bhyram Ghât. The velocity calculated from two miles fall of the stream at Ramserai Ghât, was 3 feet per second. The course of the two miles is very winding, so that the true fall and true velocity in high floods, when the waters are rushing straight across the inundated lands is greater. In the maximum Oudh flood of September, 1863, the velocity was measured by current meter, and found to be 4·4 feet per second, and the flood section 4,036. The flood discharge on that (extraordinary) occasion was therefore 17,758 cubic feet. It is difficult to judge exactly from the map of the drainage area of this river; but the length seems to be 60 miles, and the average width certainly 6 miles, probably more. Take $6 \times 60 = 360$ square miles. Then $D = 85840$ cubic feet.

Or nearly five times the maximum flood discharge actually measured during the extraordinary Oudh flood of 1863, and I believe the area of catchment basin assumed above is *well* under what the map seems to show.

These three last instances fully bear out the conclusion arrived at, from a consideration of the conditions of the Sye nullah: that in designing bridges for any of the Oudh rivers, any result based upon the apparent area of the catchment basin cannot be depended upon, and that if calculations on this basis *are* made, the result thus obtained should be reduced at least by two-thirds to ascertain the flood discharge for which provision should be made.

C. W. H.

LUCKNOW,
21*st June*, 1866.

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No. CXXVI.

THE BOMBAY WATER WORKS.

Description of the Works, recently executed, for the Water Supply of Bombay. By HENRY CONYBEARE, M. Inst. C.E. *Abridged from the Minutes of Proceedings of the Institute of Civil Engineers for* 1857-58.

EVER since the establishment of overland communication with Hindostan, Bombay has been characterized in India as the "rising presidency;" and the population of its capital has, of late years, increased in a more rapid ratio, than that of any other city in the old world. In 1833, the population was only 254,000; in 1850, it had increased to 556,000; and in 1855, it was estimated by the local government at 670,000. This rapid increase in the population, and in the importance of Bombay, is due to the advantages of its geographical position, as the nearest point of contact with Europe, and also to the excellence of its harbour—one of the finest in the world—resembling, it its configuration, the harbour of New York. Its importance and population will be still further increased, in an incalculable ratio, by the completion of the great trunk lines of railway now in progress, and which converge on the harbour of Bombay, from all points of the interior.

The water supply of Bombay had always been as deficient in quantity, as it was bad in quality; and as the population thus rapidly increased, the deficiency became occasionally so grievous, and the recurrence of the visitations, locally known as water-famines, so frequent, as to occasion the most serious alarm, both to the Government and to the public. It was evident, that a total failure in the supply, and the consequent death of tens

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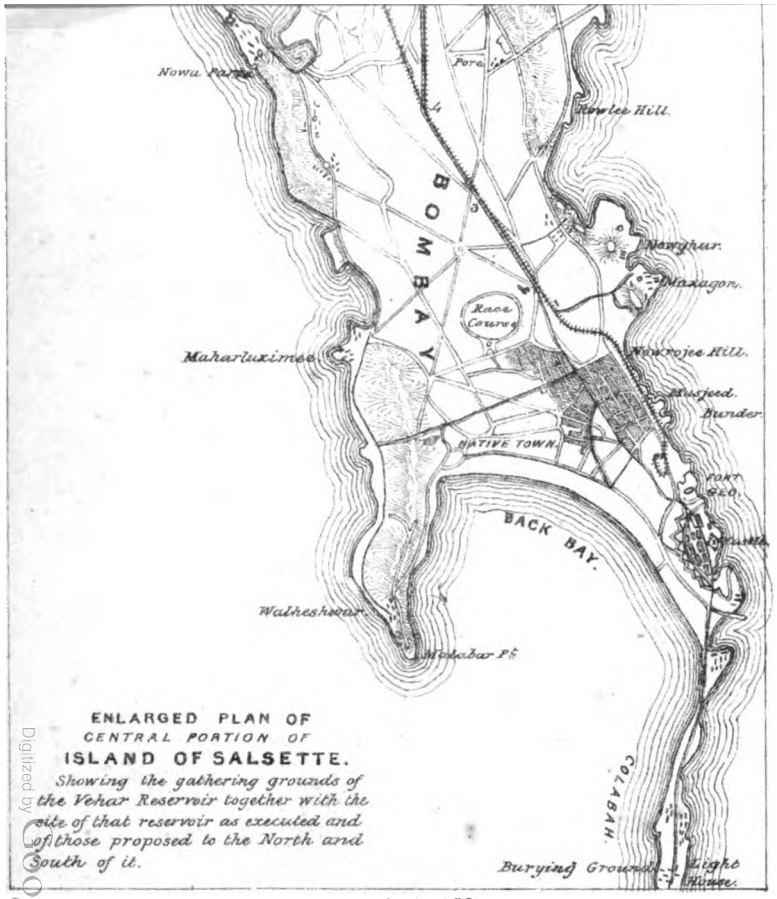
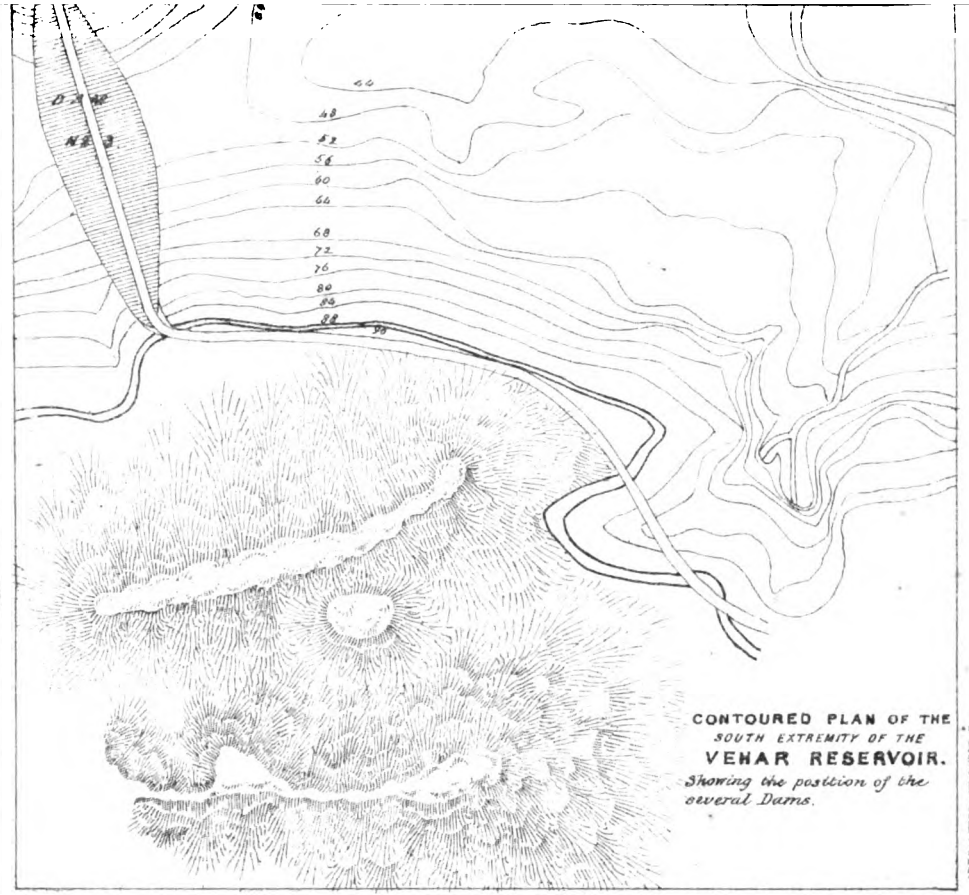


ENLARGED PLAN OF
CENTRAL PORTION OF
ISLAND OF SALSETTE.
Showing the gathering grounds of the Vehar Reservoir together with the site of that reservoir as executed and of those proposed to the North and South of it.

Scale of Miles.
Furlongs 1 0 1 2 3 MILES.



CONTOURED PLAN OF THE
SOUTH EXTREMITY OF THE
VEHAR RESERVOIR.
Showing the position of the several Dams.

Scale, 400 feet to 1 inch.
40' 50' 0' 100' 200' 300' 400' 500' 600' 700' 800' 900' 1000' feet.
Vertical Equidistance of Contours 4 feet.

PLATE XLVIII.

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of thousands, by absolute thirst, was by no means an impossible contingency, in the event of the recurrence of any failure of the periodic rains, as severe as some that had occurred when the population of Bombay was scarcely a quarter of its present amount. In seasons of scarcity, water was imported into Bombay, in boats and steamers, from the Island of Elephanta, and the resources of the railway were taxed to the utmost, in bringing in a still greater quantity from Salsette.

The Island of Bombay is situated in the midst of the great basalt formation of Western India. It is formed by two low, wooded ranges of basalt, seven or eight miles long, running nearly parallel, at a distance of about two miles apart, and enclosing between them a clay flat, generally below the level of the highest tides. At their northern and southern extremities, these parallel ranges are united, by raised beaches of sand (now forming a littoral concrete), rising but a few feet above the sea level; and each of these raised beaches forms the margin of a land-locked bay, fringed by cocoa-nut plantations. These natural boundaries were formerly breached by the sea in several places, and the space they enclosed, comprising about three-fourths of the present area of the island, was consequently a salt-water lagoon. The breaches have, for many years past, been made good by embankments and sluices, and the lagoon thereby converted into a salt marsh, which is covered with fresh water every rainy season, and is thus being gradually brought into rice cultivation. The Island of Bombay has been connected with the adjoining islands of Trombay and Salsette (from which it is only separated by a mangrove marsh), by three causeways; and a railway bridge now unites the latter island to the continent of India. From 80 inches to 100 inches of rain-fall annually at Bombay between the 10th of June and the 20th of September, the remaining eight months and a half being without rain.

Under such geological and hydrographical conditions, a supply of water from springs was not to be expected. The population of Bombay was, consequently, mainly dependent for water during nine months out of the twelve on the rain caught, during the monsoon, in old quarries, and other shallow excavations, which, being situated in the midst of a peculiarly dense and dirty population, became so thoroughly contaminated, as the dry season advanced, that a charge "for clearing dead fish from the tanks" was an item of annual recurrence in the accounts of the municipality. It is evident, that water so impure as to kill the fish it contained, could not

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be drunk with impunity; and there is no doubt, but that the annual prevalence of cholera at Bombay, towards the close of the dry season, was mainly due to the extreme pollution of the only water the lower classes could then obtain. The Registrar-General's Report for 1850, affords conclusive testimony, as to the connection between cholera and impure drinking water in London; Dr. Gavin also states, that "the connection between foul drinking water and cholera is established by irrefragable evidence."

The first project for increasing the water supply of Bombay, by means of surface collection in the adjacent high grounds (obviously the only practicable plan in the case of Bombay), is due to Colonel Sykes, late Chairman of the Hon. East India Company. He proposed, nearly thirty years ago, to collect and impound the rain-water falling on the high ground at the south-western extremity of the Island of Bombay. This would, at that time, have afforded a most valuable addition to the water supply, but now it would be altogether inadequate. Colonel Sykes' plan was revived by Colonel Jervis in 1845, but without any material alteration. The second feasible scheme was that of the late Mr. Rivett, who proposed to bring the water collected and stored in the high grounds of the adjacent Island of Trombay. In 1846, Major Crawford, of the Bombay Engineers, pointed out the capabilities of the Valley of the Goper, in the adjoining Island of Salsette. This is obviously the natural, and the only adequate, source, for the water supply of Bombay, by means of surface collection. When a town is to be supplied with water on this system, and by gravitation, the valley, or valleys, debouching in the neighbourhood should be traced upwards, until some natural basin is found, at a sufficient elevation above the town, in which an adequate body of water may be collected and impounded, in storage reservoirs, by a moderate amount of embanking. The only valley answering these conditions, in the neighbourhood of Bombay, is that of the Goper. The parallel ranges which, together with the salt marsh they enclose, constitute the Island of Bombay, are merely prolongations of the boundary ranges of the Valley of the Goper; so that when swollen with floods, the waters of that stream used formerly to enter the salt marshes of Bombay, through the breaches that then existed in the northern embankments, and traversed the whole length of the island, on their way to the sea.* The central plateau of Salsette,

* *Vide* "Hamilton's Gazetteer.

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which is drained by the Goper and its affluents, is bounded and intersected by ranges of hills, amongst which the occurrence of favorable sites for the storage of water might be certainly predicated.

The Goper scheme lay dormant, with the others, until the water famine of 1851. Lieutenant De Lisle was then instructed to make a preliminary survey of the valley; and soon after, the question was referred to the Author, whose report on "the amount of the existing water supply of Bombay, and the various means which had been proposed, or might be adopted, for increasing it," was published by the Bombay government. The conclusion arrived at was, that the Valley of the Goper was the only possible source whence an adequate supply could be obtained. It was recommended, that detailed contour surveys should be made, with the view of determining the capacity of whatever eligible sites for water storage it afforded; and that plans and estimates should be prepared, to ascertain the cost of rendering a supply from this source available to the population of Bombay. The course, thus recommended, was adopted by the Government, and the Author was selected as the Engineer, to prepare the surveys and estimates, and to design and execute the works.

The quantity of water required for the supply of Bombay was estimated at four thousand million of gallons annually. At the rate of twenty gallons per head per day, this supply would indeed only suffice for a population of half a million, and the population of Bombay was estimated at nearly 700,000; but, it was argued, that the proposed supply would be in addition to that derived from existing sources, and that there were peremptory pecuniary reasons for keeping down the outlay, as much as possible. On the other hand, it was admitted, that the extraordinarily rapid rate at which the population was increasing, rendered it imperative that the works should be designed with a special view to the necessity of their future extension, as the population increased.

On referring to the plan it will be seen, that the high ground, in which the Goper takes its rise, affords five admirable sites for storage reservoirs; two of which, the basins of Vehar and of Poway, are as large as lakes. The most northern of these reservoir sites is in the immediate neighbourhood of the celebrated cave temples of Kenerry, at the head of an adjoining valley; so that it will have to be connected with the Goper series of reservoirs, by a short length of syphon main. Of these basins, that of Vehar is the most capacious; but a measurement of the gathering-grounds, and

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contour surveys of the basin, were necessary, to determine whether the former was adequate to the collection, and the latter sufficiently capacious for the storage, of the annual water supply required, and also at what cost the supply, that might be so afforded, could be made available for public use. The result of such investigation satisfied the Author, that the Vehar basin was adequate to the collection and storage of all the water that could be required for some years, and the works for water storage, were therefore confined, in the first instance, to the construction of this single artificial lake. It was, however, arranged, that while these works were in progress, contour surveys of the other reservoir sites should be carried out, so as to determine to what extent, and at what cost, the supply might be at any time increased, by the construction of any one or of all of them.

It was essential, that the rain-fall, annually available from the area of the gathering grounds, should exceed, by a safe margin, the annual consumption, waste, and loss from evaporation, but there was no objection to the capacity of the storage reservoirs exceeding the available rain-fall of a single year. On the contrary, it was most desirable that the storage reservoirs should be made as capacious as possible, in order to contain a reserve, sufficient to meet the contingency of a deficient monsoon.

It was assumed, that six-tenths of the annual rain-fall on the Vehar gathering-grounds might be considered available for the supply of the storage reservoirs. The area draining into the Vehar basin, above the sites of the impounding dams, is 3,948 acres; if necessary, this area might be enlarged to 5,500 acres, by the extension of catchwater drains along the western slopes of the hill boundary, both to the west and on the north of the reservoir.

The mean annual rain-fall, at the level of the sea, at Tannah, five miles and a half distant from the Vehar gathering-grounds, is 124 inches. It is well known that, at high levels, the rain-fall is greater than over comparatively low-lying districts. The mean level of the Vehar gathering-grounds is at least 300 feet above the sea; and the wooded ranges that form the boundary of the basin have summits of from 800 to 1,600 feet in height. It was considered, that the rain-fall, available for the supply of the reservoirs, might be safely assumed at six-tenths of 124 inches, or 74·4 inches over the area of the gathering-grounds. At this rate the supply, available from 3,948 acres of gathering ground, would be upwards of six thousand six hundred million gallons; and that available from 5,500

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acres about nine thousand million gallons. These quantities evidently exceed the requirements of Bombay for some years to come.

The storage capacity of the Vehar reservoir, which is fed by the gathering-grounds above described, is ten thousand eight hundred million gallons; deducting from this the loss from evaporation, which, at 6 inches per month for the eight dry months of the year, would amount to a little more than one thousand million gallons, there would remain nine thousand eight hundred million gallons, available for consumption. As the annual rain-fall on the gathering-grounds available for storage, greatly exceeds the annual consumption of Bombay, the water will continue to rise in the lake, notwithstanding the drain of the town, from the commencement of the rains until near their termination; or say for three months, leaving only nine months' consumption to be provided for, until the rainy season comes round again. Nine months' consumption for a population of 700,000, at the rate of twenty gallons per head per day, is rather more than three thousand seven hundred million gallons, and deducting this from the storage capacity of the lake, less the evaporation, upwards of six thousand million gallons, or nearly two years' supply, would remain in the lake as a reserve.

When filled up to the level of the waste weir, the maximum depth of the Vehar lake is 80 feet. It covers an area of 1,394 acres, and stands 180 feet above the general level of Bombay. The particulars of the three Dams, by which the water in the lake is impounded, are as follows:—

Dams.	Extreme height.	Extreme length at the top.	Earthwork.	Puddle.	Total of earthwork and puddle.	Broken stones, under pitching.	Rough stone pitching.
	Feet.	Feet.	Cubic Yards.	Cubic Yards.	Cubic Yards.	Cubic Yards.	Square Yards.
No. 1	84	835	255,706	30,910	286,616	997	26,998
„ 2	42	555	43,617	10,332	53,949	327	8,827
„ 3	49	936	106,743	14,717	121,460	659	17,797
Totals, ...			406,066	55,959	462,025	1,983	53,617

The principal Dam contains a little under 300,000 cubic yards. The top width of the embankment No. 1 (which has to carry a road) is 24 feet; that of the two others is 20 feet. The inner slope of all three embankments is 3 horizontal to 1 vertical, and the outer slope 2½ to 1. These embankments were specified to be formed in regular layers of not more

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than 6 inches in thickness, each properly watered, punned, and consolidated. The puddle-walls of all the embankments are 10 feet wide at the top, and have a regular batter on each side, at the rate of 1 in 8. The trenches for the foundations have been excavated through the surface rock, and past all surface springs, into the solid basalt below. The slopes of all the embankments, and also the top surface, are covered with stone pitching, at least 12 inches in depth, roughly squared by the hammer, and solidly set by hand; an additional thickness of 12 inches of broken stone being laid underneath. The pitching of the top surface and of the external slopes of the dams is necessary to protect the slopes from the effect of the heavy down-pour, to which the hill districts of India are subject, during the rainy season; the duration of the intervening dry season being too great to allow of their protection, by means of turfing, or vegetation.

The Waste weir is 358 feet in length. It has a horizontal top width of 20 feet; and is faced throughout with chisel-dressed ashlar, set in cement. A breakwater is affixed to the inner margin of the waste weir, to prevent the water being blown over in high winds.

The water is drawn from the reservoir through a Tower, provided with four inlets, fixed at vertical intervals of 16 feet apart. These inlets are 41 inches in diameter, and are provided with conical plug seats, faced with gun-metal. The three inlets not in use are kept closed by conical plugs, fitted by grinding. These plugs are suspended exactly over their seats from the balcony above, and are raised, or lowered, at will, by crane-work at the top of the tower. The inlet in use is surmounted by a wrought-iron straining cage, covered with No. 30 gauze copper wire, and fixed to a conical ring, fitting into the inlet orifice, in the same manner as the plugs, and equally capable of being raised and lowered at pleasure. This strainer presents a surface of 54 square feet. The gauze is affixed to the cage, so as to admit of its being changed from a boat, when clogged, in ten minutes after the cage has been drawn up to the surface—or a plug may be substituted for the cage, and lowered to its place in the same time. At the bottom of the inlet well, and exactly over the orifice of the supply main, another conical seat is fixed, into which a similar straining cage (but with No. 40 gauge copper wire, and presenting a surface of 90 square feet) is inserted. The water thus passes through two strainers, before it starts for Bombay. The primary object of this arrangement was to obtain, in the

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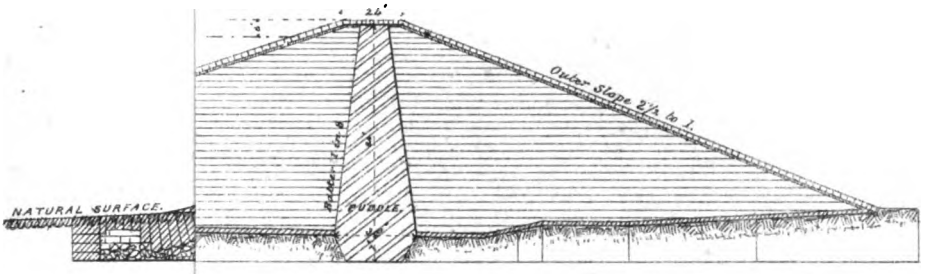
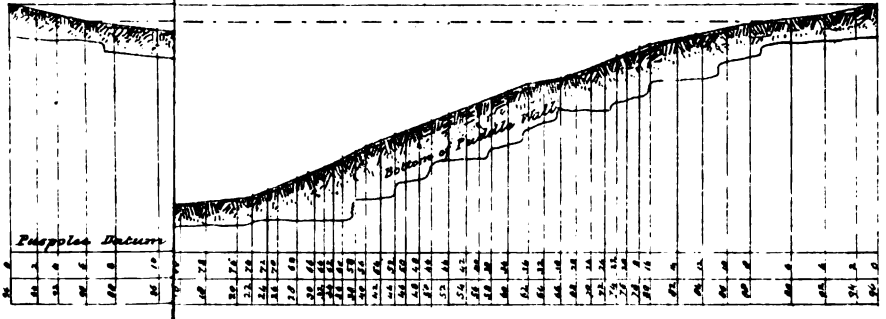
ECTION OF EMBANKMENT Nº 1. ON LINE A.B.



Scale.



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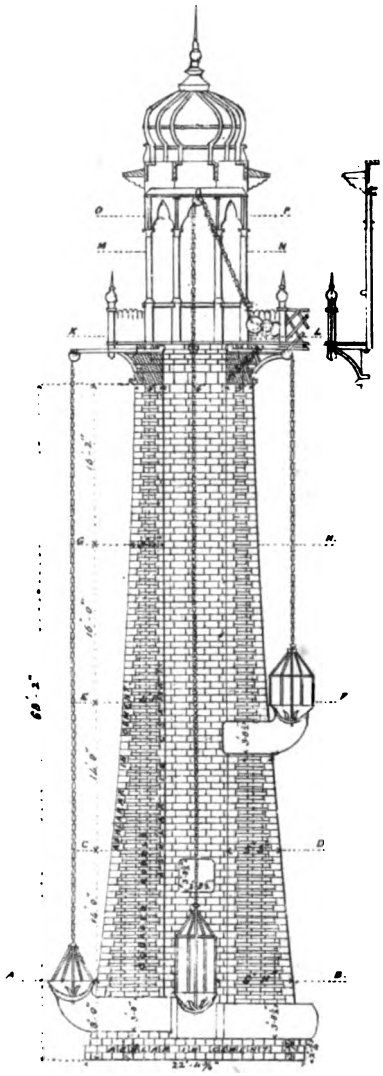
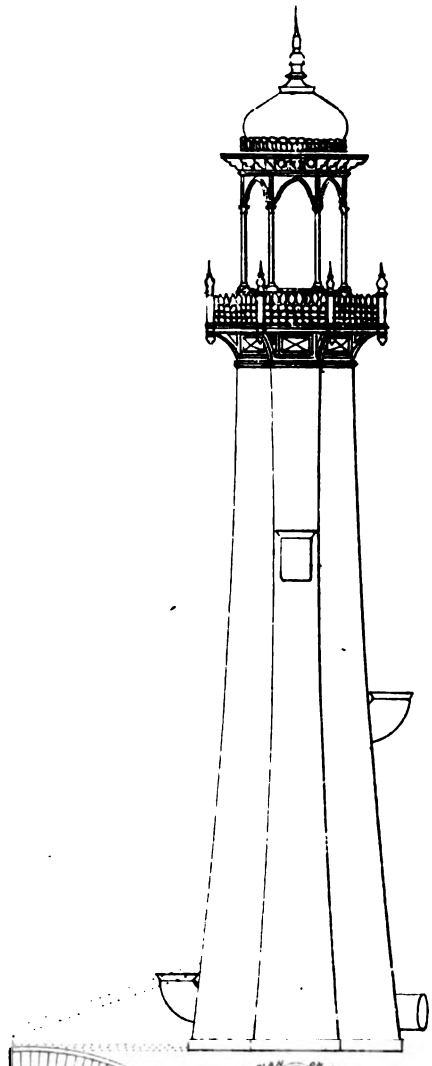
BOMBAY WATER WORKS.

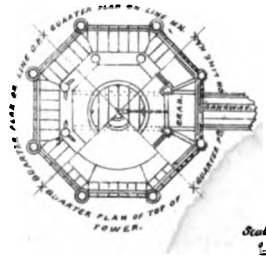
INLET TOWER.

SECTION.



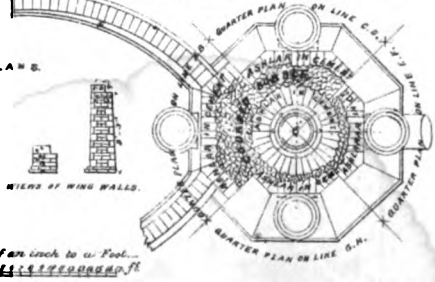
ELEVATION.





PLANS.

END WINGS OF WING WALLS.



Scale $\frac{1}{16}$ of an inch to a Foot.

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town distribution, the benefit of the additional head of water—due to the depth of the lake, which would have been lost had the water been strained (as in the more usual arrangement) at the outside foot of the dam. It was also thought advisable to avoid the use of such heavy sluice-valves as would be required for closing inlets 41 inches in diameter, in positions in which it would be difficult to get at them, for the purpose of effecting any necessary repair. Without this arrangement, the utmost head obtainable would have been insufficient for a distribution by gravitation alone.

The gathering grounds are of basalt. The surface, where not covered deeply by the waters of the lake, rises with so steep an acclivity, as to have been long since denuded of any soil that could be washed away. The vegetation is all evergreen, and no human habitation is permitted, throughout the entire area of the gathering-grounds. Under these conditions, and also taking the great depth and capacity of the lake into account, the Author decided that filtration would be altogether superfluous. For the same reason, a sludge-pipe to drain the lowest level of the reservoir was deemed unnecessary. No considerable deposit is anticipated over any portion of the bottom; the little that takes place will probably be confined to the head of the lake, some miles distant from the outlet; and were it otherwise, a single sludge-pipe could have no appreciable effect, in keeping down, or scouring off, the deposit over an area of 1,400 acres.

The supply main, traversing the dam, is 41 inches interior diameter, and the metal is $1\frac{3}{4}$-inch thick. It is laid in a level trench, excavated in the rock, and filled with concrete. The portion traversing the puddle trench is supported on ashlar masonry, set in cement, puddled to a depth of 6 inches, and then arched over with four rings of brick in cement; two teak-wood washers being affixed transversely on the pipes, to prevent any water from passing between the pipes and the puddle.

At the sluice-house, situated at the outside foot of the dam, the large main, 41 inches in diameter, bifurcates into two mains, each 32 inches in diameter, both of which are eventually to be continued into Bombay; only one has been laid, in the first instance, as that suffices for the present requirements of the population. The length of the pipe, of 32 inches diameter, between the Vehar Lake and Bombay is 13 miles 6 furlongs and 160 yards, of which the last 7 miles are laid alongside the Great

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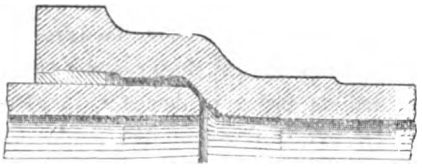
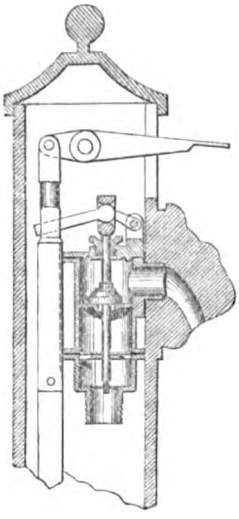
Indian Peninsula Railway. The mode of joining the pipes is shown in Fig. 1. The supply is distributed through the town and suburbs, by means of branch and street mains, in the usual manner. The only peculiarity in the distribution, is the large proportion of the population supplied gratuitously, by means of self-closing public conduits (Fig. 2). The design of these appliances was, therefore, the subject of much consideration. The pattern finally adopted can be made to close either with, or against, the water pressure, by simply taking out and reversing the spindle valve; the counter weights admit of being exactly adjusted to the resistance, at the various levels of the town, so as to leave in each case, whether closing with, or against the water-pressure, just so much preponderance as may be found sufficient to close the valves.





The contracts for the reservoir works in Salsette, and for all the pipe-laying, were let to Messrs. Bray and Champney, of Leeds. The pipe contracts were executed by Messrs. D. Y. Stewart and Company, of Glasgow. All the larger sizes of sluice valves, the hydrants, and a portion of the special castings were manufactured by Messrs. Simpson, of the Belgrave Iron Works, Pimlico. The sluice valves, 32 inches in diameter, are admirable specimens of workmanship. The valve is made in two segments, the smaller one being about one-fourth the area of the larger. By this arrangement, the valves are rendered capable of being closed or open under the severest pressure, with a very trifling exertion of force. The smaller valves are on Underhay's system, which possesses the advantage of allowing the valve seat, as well as the valve itself to be removed for the purpose of repair, without disturbing the laying of any portion of the mains. The water is delivered at Bombay under a pressure varying from 165 feet to 180 feet.

The conditions under which the work had to be executed were somewhat

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peculiar. The want of water was so grievously felt at Bombay, that the Government and the public were impatient for the immediate completion of the works. But all the pipes and machinery had to be manufactured at a distance of 15,000 miles from Bombay, and it was a difficult matter to provide shipping to a single port, for so large an amount of dead weight, within so short an interval. Moreover, it was only during the eight months of the fair season, from the 1st of October to the 1st of June, that work could be carried on to any extent in the interior of Salsette. During October and November, while the ground was drying up after the rains, jungle fever of an extremely malignant type prevailed in that locality, to an extent to create a very serious impediment to the effective prosecution of any large works. In the high country of Salsette, the rains are too heavy and continuous to allow of any work being carried on while they prevail; and the torrent that often pours down the gorge of the Goper at that season would inevitably sweep away any works for impounding its waters, left in an incomplete state when the rains set in, unless some provisional outlets were provided for its escape in some other direction.

It was evident, that during the first fair season, the operations could not be sufficiently extended to allow of the completion of the impounding works to the height of the intended waste weir, before the setting in of the ensuing rains. The excavation for the foundations for the puddle walls of the main dam had to be carried through from 15 feet to 25 feet of extremely hard basalt, full of fissures, before it could reach the impermeable rock below. And as the bed of the Goper contained water up to the middle of February, and the rock immediately below the surface, in the gorge that drains the basin of the Goper, was permeated by the infiltration of the entire area of the basin, it was certain that the excavation would be difficult, and that a great deal of water would have to be encountered. These difficulties limited the height to which the dam could be raised before the rains set in; and it was, therefore, necessary to provide a temporary escape-weir, by keeping open the existing gap in the enceinte of the basin, which it was ultimately intended to close by Dam No. 2. As the water could not escape by this outlet until it had reached the 56-feet contour, it was essential that Dams No. 1 and No. 3 should be carried to a safe height above this contour before the setting in of the rains. It was, therefore, stipulated by the Author, in the specifications and the

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contract deed, that during the first fair season's operations, Dams Nos. 1 and 3 should be raised to the height of the 70-feet contour; the site of Dam No. 2 remaining untouched until after the first rains, to serve as a temporary escape weir. By this plan, the water falling during the first rains occurring after the commencement of the works, were impounded in the reservoir to the height of the 56-feet contour. It was specified that the laying of the conduit pipe should be simultaneously proceeded with, so as to render the water, so impounded during the first monsoon, available to the wants of Bombay during the ensuing dry season, and that by the termination of the second fair season, on the 7th of June 1858, all the works, including the town distribution, should be fully and satisfactorily completed.

These arrangements were in all essential points successfully carried out. The Dams were just completed to the height required to insure safety, before the setting in of the first monsoon; the rain-fall of which first monsoon was thus impounded and stored to the 56-feet contour; and the works will be in a complete state to receive the rains, commencing in June next, by which rain-fall the lake will be filled to the waste weir, and its surface extended over an area of 1,394 acres.

The only contretemps that has occurred, has been occasioned by the difficulty experienced in providing shipping for the pipes with sufficient rapidity, but the effect of this delay will be merely to retard the completion of the detailed distribution in the town to some weeks beyond the specified date, which, as such delay will operate during the rainy season, when water is only too abundant, will be attended by no practical inconvenience.

Much difficulty was experienced in raising the principal dam to the height required to insure safety, before the setting in of the first monsoon, June 1857. The Contractor had arrived at Bombay at the commencement of the fair season of 1856-57, but the locality and the season were so unhealthy, that the works at the reservoir could not be commenced in earnest, before the beginning of December 1856. On the 15th of that month, there were, however, upwards of two thousand men employed in the excavation of the trench for the conduit pipe, and fifteen hundred men and one hundred and seventy carts on the principal dam at Vehar. The excavation for the puddle wall already occasioned much anxiety, from the hardness of the rock and the volume of the surface springs, which were formidable obstacles to the progress of the work. These difficulties in-

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creased as the excavation proceeded, until the engine-power employed was barely sufficient to keep down the water. A thoroughly impermeable foundation for the puddle wall was not attained throughout its entire length, until the commencement of March, or very close upon the rainy season; so that the Resident Engineer's bi-monthly progress reports were most anxiously looked for by the Author. All difficulties were, however, surmounted, by the ability of the engineering staff, and by the energy of the Contractor. On the 16th of June the dam had reached the height required to insure safety, although the rains had commenced five days earlier; but that still left a considerable margin for safety, for the rain-fall had to fill the lake to the 56-feet contour before any damage could be occasioned to the dam, and the main-pipe of 41 inches diameter, was all the time discharging a river of no contemptible volume. Notwithstanding this, the rain-fall of two days, the 22nd and 23rd of June, on a gathering-ground of 4,000 acres, sufficed to add one million two hundred thousand gallons to the contents of the reservoir. As soon as the water had attained the level of the 56-feet contour, and escaped freely through the gap in the hills which served as the temporary waste weir, measures were taken for closing the pipe, of 41 inches diameter, and for retaining the water in the reservoir, to meet the requirements of Bombay during the ensuing dry season.

Since the termination of the last rains, the level of the lake has kept up remarkably well, its surface not having lowered more than 6 inches per month. This loss is stated to be principally due to leakage through the temporary plug by which the conical orifice of the pipe 41 inches in diameter is at present closed. No leakage whatever is perceptible through either of the dams. The small amount of this monthly loss proves how inapplicable the result of observatory experiments on evaporation, on a small scale, are to the circumstances of a large body of water, such as that constituting the Vehar Lake.

H. C.

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No. CXXVII.

FINANCIAL RESULTS OF MADRAS CANALS.

Memorandum by LIEUT.-COLONEL. J. C. ANDERSON, R.E., *from the Report of the Ganges Canal Committee.*

I AM quite willing to accept Sir A. Cotton's estimate of the benefits derived from the Godavery and Kistna works. But I am of opinion that these works were carried out under exceptionally favorable circumstances; and that there are few, if any, non-Delta formations in India where the same results could be attained at the same proportional expense. Not only would Government be disappointed were they to take the returns from the Madras Deltas, as the standard which properly managed irrigationed works ought generally to yield, but private companies might be led, through the same mistake, to embark in schemes which a real knowledge of the Delta works would have shown them, could not be of an equally profitable character. In the belief that a description of the peculiar advantages under which the Godavery and Kistna works were executed will not only be useful in clearing away much mis-apprehension that prevails regarding them, but will help the Government to understand better than they seem to do at present, the cause of their yielding a much higher rate of profit than the irrigation works in the North of India, I proceed to impart such information as I possess on the subject.

In the Godavery and Kistna Deltas, irrigation from old channels was carried on to a considerable extent before the new works were commenced. In the reports on the Godavery, frequently allusion is made to the old channels. They are described as being very imperfect, as they opened

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from the river bank on a high level, which rendered them liable either to get an insufficient supply when the river was low, or an excessive one when it was high. The actual value of the channels however was not only considerable, but they afforded the means of at once distributing the water from the new main channels, and they possessed an agricultural class ready to use it as soon as it was offered them. The new works were thus enabled to return a profit much earlier than they could have done, had an entirely new system of distribution channels formed a part of the project.

That the old channels in question must have been valuable adjuncts to the new works, is shown very clearly in the following extract from Captain Orr's Report. "By what has been shown as the benefit derivable from the anicut by means of the channels immediately affected by it, it will be seen, that with an expenditure of 9 lakhs, an annual increase (calculated on the lowest data) of Rs. 1,09,451 would be obtained, a result of itself sufficient to justify the construction of the anicut."

In the Kistna Delta there were not only irrigation channels of considerable size, but a large number of tanks, both of which have been of invaluable service to the new works. Of the channels I may particularize the Pullairoo in the northern section of the Delta. Though now of moderate size, about 50 feet near the head, it is evidently an ancient arm of the river, running on a ridge like the Kistna itself, and admirably adapted for distributing the water for irrigation. It sufficed by means of numerous small branches to irrigate a large proportion of the Delta; that is when it had water. Before the construction of the anicut at Bezwada, it was liable like the channels in the Godavery, to receive either an insufficient or excessive supply, according as the freshes might be below or above the average, and like them and the channels in Tanjore, it only wanted a regular supply to secure the revenue due to the whole of the land under it. This want, the anicut, combined with a new head 15 miles in length, supplied, and the desired result was at once attained. The importance of this channel and its value to the new system may be understood from the fact, that when 65,000 rupees had been expended in the course of about eight years subsequently to the admission of water from the anicut, solely for clearance and repairs of the channel and its branches, 6,500 rupees only had been expended during the same period in new works and improvements. The cost of repairs to the Delta channels is under 8 annas per acre of irrigated area, and the water-rent was until lately 8 rupees per

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acre, or six times as much. The large expenditure on repairs therefore represents a large irrigated area.

Another channel existed in the southern section of the Delta and conveyed water to a number of important tanks to supplement the supply from the local rain-fed streams. A cut of 12 miles in length connected it with the anicut, and changed its supply from a variable and uncertain quantity to a certain and uniform quantity. There were 17 tanks under this channel, and the average revenue derived from them, from 1851 to 1855, that is for four years prior to the introduction of a supply from the anicut, amounted to Rs. 52,929, the minimum being Rs. 31,458, and the maximum Rs. 70,092. The revenue derived from the same tanks in 1863, the last year of which I possess the accounts, was Rs. 1,39,323, showing an increase over the former average of Rs. 86,394. The fluctuation of the revenue before the admission of water from the anicut was very remarkable; thus in the course of four years only, four of the tanks yielded respectively a minimum revenue of Rs. 0, Rs. 10, Rs. 323, and Rs. 123, and a maximum of Rs. 3,321, Rs. 2,908, Rs. 3,663, and Rs. 6,327.

The supply of the tanks was formerly very precarious, and the above examples testify to what extent both Government and the Ryots were liable to suffer. The immediate effect of the more certain supply from the anicut was to give confidence to the Ryots, to secure the revenue at the highest figure to which it could have risen had the tanks received a good supply from rain, and by doing away with all risk of loss to the cultivators, to induce an extension of the cultivation, and a further increase of revenue. But without the aid of the tanks and the channels leading to them, which were, as I may say, superadded *gratis* to the anicut works, the same increase of revenue could not have been attained, except by a large additional expenditure on new channels or tanks, and a delay of several years.

Besides the above, there are another series of tanks in the Kistna Delta which were fed by a number of small channels from the river. A short branch from the new main channel into a cutting which had been formed to make an embankment along the river, fed these tanks with a regular, instead of their former precarious, supply, and a large increase of revenue was the result.

It will thus be seen that the Godavery, and still more the Kistna, Delta works, started in possession of some advantages over an entirely new system of works like the Ganges Canal, where not a single village channel existed

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along the length and breadth of the country to be irrigated, and where the cultivators were unused to any other mode of irrigation but that by means of wells.

The Godavery and Kistna works have other advantages in regard to the alignment of new channels, which alone would render a comparison between them and the canals in the N. W. Provinces, altogether unfair.

The anicuts which have been constructed across the Godavery and Kistna are about 14 and 19 feet, rsepectively, above the bed, and the ground along the banks may be from 13 to 17 feet above the crest of the anicuts. The heads of the main channels are between 5 and 6 feet lower than the crest, consequently the depth of cutting will be from 18 to 22 or 23 feet. If this depth of cutting had to be maintained for any considerable distance, the expense of conveying the large body of water required for the irrigation of the Delta would be very great. But the fact of the country to be irrigated being liable to periodical inundation by the river from a remote period, implies that the deposits during a series of years have raised the land along the banks to a higher level than that at a distance from them, so that the deep cutting at the head of the main channels works out into a moderate and inexpensive cutting in the course of a few miles.

Sir A. Cotton in one of his early reports on the Godavery, thus describes the peculiarities I have mentioned:—"Besides the slope of the land towards the sea in a Delta, it has another slope, viz., a fall from the river in a direction perpendicular to its course, and the fall is much more rapid than that towards the sea. In the present case it has been ascertained to be, near the head of the Delta, 16 feet in two miles from the west, and 7 feet in two and a half miles on the east side. Thirteen miles lower down, that is twenty-five miles from the sea, the fall is 9 feet in two and a half miles on the west side of the Godavery. Thus the river banks form a ridge from 18 to 7 feet above the level of the land, at the distance of from three-quarters to two and a half miles distant on either side, providing most remarkably for the leading out of the water upon the lands.

"The apparently formidable operation of bringing the water from the bed of the river is, upon an examination of the level, reduced to this, that the highest part of the Delta is only 8 or 10 feet above the bed of the river in its immediate neighbourhood, that is within two miles of it; and that if an anicut be built 11 feet high above the deep channel of the river, the deepest excavation for the irrigating channels will be 18 feet, and that

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within two miles, the country on the west side would be below the level of the top of the anicut. On the east side the lands would be on the same level within about four miles. The apparent objection arising from the great depth of the river is thus completely disposed of."

On the Ganges Canal the water before reaching the tract of country requiring irrigation, had to be carried across a series of formidable torrents, which required a vast expenditure of time and money. Had the canal been opened from the river below the point where the last of the torrents joins it, it would have had to traverse a distance of 50 or 60 miles before the irrigation limit could be attained. In either case heavy expenditure was necessarily entailed before the water could be turned to any use.

The main channels in the Godavery and Kistna are simple cuttings, unimpeded by any natural difficulties. Combined with the anicuts, these short cuts carry the water to the points from which it may be distributed to every field in advance, to near the sea, and the distribution channels have not to extend beyond an average distance of 30 or 40 miles.

On the Ganges Canal the water is conveyed over much more unfavorable ground to a distance of 350 miles from the head. Sir A. Cotton considers this fact as one of the errors of the original project. The practicability of forming separate heads between Roorkee and Cawnpore in order to reduce the distance to which water is conveyed, without being utilized, forms the subject of separate enquiry. I may remark in this place, that the principal object of the Ganges Canal was to ameliorate a famine, and with this object the water was distributed in a certain proportion over a much larger tract of country than was economically necessary. Had it not been for the restriction thus laid on the projector, he could have utilized the whole of the available supply of water in a canal of one-half or one-third the length to which it has been actually carried, and would have had the opportunity of effecting a large saving in the cost of the work.

There are several other facts which serve to explain in some measure the high and quick returns yielded by the Godavery and Kistna works. There is an enormous extent of waste land in the Deltas; the great mass of it is either sandy or more or less swamp, but large tracts not far removed from the sea, and recently inundated by it, are unfit for cultivation until the soil is improved. Both this and the sandy soil, however, become as valuable as any other land in the Deltas, after several floodings by the river water, loaded as it is with mud of the most fertilizing character.

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Large tracts are thus rendered productive, which in their natural state were absolutely useless. A further extent of country is brought within the influence of the Delta channels by embanking or draining swamps. It is a common occurrence for 1,000 or even 2,000 acres of such waste land to be taken up in one plot for rice cultivation in a single season; and there is one instance in the Kistna Delta, of the Ryots of a number of villages uniting to present an agreement, to take up in one block 15,000 acres of waste land as soon as certain drainage and irrigation channels should be completed, and to pay Government rent for it at the rate of Rs. 6 per acre, or Rs. 90,000 in all per annum. This is no exaggeration, as the land was actually taken up on those terms as fast as the drainage and irrigation works progressed.

The canals in the N. W. Provinces have no such advantages. Not only is the area of waste culturable land, in the Doab between the Ganges and Jumna, of comparatively small extent, but the revenue settlement extends over a period of 30 years, and the cultivator has to pay no more for irrigating waste land, than the small water-rate which he has to pay for land already under cultivation.

But on the other hand, high as the returns have been from the Delta works, they would have been far higher had the works experienced a tithe of the liberality with which the Ganges Canal has been treated from first to last. Notwithstanding the Government have received incontestible proofs of great and manifold advantages having accrued, both to themselves and to the country, from the extension of irrigation in the Madras presidency, the works which above all others may be taken as the type of what can be accomplished when a supply of water can be cheaply distributed, are only half finished.

The Government readily sanction the estimates for the various new works and extensions that are submitted to them, but the money to carry them out is not forthcoming. Not even the modest demand of the local officers for a fixed and regular annual allotment of 5 lakhs of rupees per annum for new works on the Godavery and Kistna united, until the Delta system shall have been fully developed, has been complied with. Channels which may have been in progress in one year, are summarily stopped the next; or if the main channels are completed, the funds required to carry out the minor works and to turn the others to profitable account, may not be granted, though the works themselves have received the complete approval

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of Government. Numerous instances could be adduced in which the delay that has thus arisen in utilizing the supply of water, has occasioned a large loss of revenue. I have described the advantages which the Delta works had at starting over the Ganges Canal, and to render the comparison a fair one, I think myself bound to take conspicuous notice of this one great disadvantage which they have had to contend against for a long succession of years.

Many of the drainage channels in the Godavery and Kistna have been used for carrying the water for irrigation. In the country affected by the Ganges canal the drainage courses are deep, and nothing would be gained by using them as irrigation channels. Had they been shallow, the local Engineers would probably still have avoided them, and would have preferred to go to the expense of excavating new channels rather than interfere with the proper function of the drainages. Allowing that there are serious disadvantages in using channels for both purposes, there can be no doubt that the Engineers in the Godavery and Kistna have secured a large additional revenue by being content to use imperfect channels, when time and money would have been required for the excavation of new ones.

The slight fall of many portions of the Deltas, combined with the system of using the natural channels for purposes of irrigation, serves to produce extensive swamping; notwithstanding this, it as a remarkable fact that the Deltas are more healthy than other parts of the district. Fever especially is far less prevalent in the Deltas than in the country immediately beyond it, where there is but little rice cultivation and no swamps. The cause is unknown to me. It can hardly be the influence of the sea air, because the formation of the east coast of India closely resembles that of other countries which are notoriously unhealthy. It is more likely, I think, to be in the geological formation of the soil. However that may be, it would be useless to attempt to prove that ill-drained rice cultivation in the N. W. Provinces should be healthy, because it is healthy in the Madras coast districts.

There are but few bridges on the Godavery and Kistna canals. In most cases bridges are built over the locks, but on several of the channels there are no bridges for 30 miles and upwards. On the Ganges Canal the bridges are built at every two or three miles apart. They have not been constructed in such profusion, simply because the Engineers thought them necessary or wished to construct them, but because the Local Government,

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acting as they would act towards a private company, insisted on having them where communications were intersected.

Sir A. Cotton's argument in favor of the procedure which has been followed in Madras seems a sound one. Doubtless, in some parts of the Deltas, considerable inconvenience is occasioned by the want of bridges, but if only a limited sum was available for expenditure, is was best that it should be used to extend the irrigation.

The actual want of bridges is not so great in the Deltas as in the N. W. Provinces, for the nature of the soil and absence of suitable material are almost prohibitory to the formation of roads which should be passable in the rains. Indeed, there are no metalled roads in the Deltas, but the numerous navigable canals supply their place along the principal lines of traffic, and any other traffic is unimportant. In the Ganges and Jumna Doab, there are greater facilities for moving carts; the extent of thickly populated country is much greater; and there is a far higher proportion of important towns and villages, than are to be found in the Godavery and Kistna. Hence, more cross communication is necessary, and we may reasonably expect that bridges at short intervals will be looked upon as a necessary addition to the canals. I may add that the canals in the N. W. Provinces, are rarely closed unless for emergent repairs, when some sacrifice of revenue is likely to be entailed; and that bridges can be built at a considerably less cost in the first instance before water is admitted, than would be possible afterwards.

Thus it appears that a considerable expenditure on account of bridges has to be borne by the Ganges Canal, while the Delta channels in Madras are relieved up to this time of any heavy charge on the same account.

In the Godavery and Kistna channels, navigation and irrigation can be carried on together more favorably than is possible on the canals in the N. W. Provinces. The principal crop in the Deltas is rice, which requires water from July to December. There is also sugar-cane and a second crop of rice in the Godavery, but the area and quantity of water consumed by them is small compared with the requirements of the others. The channels are aligned with a slight fall, generally from 3 to 6 inches a mile, and locks are placed at such intervals as will allow of still water navigation, when the water is not required for irrigation.

The surface fall of the channels does not necessarily correspond with the fall of the bed. For three or four months in the year, July to October, it

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may be increased to 9 inches per mile. The velocity, especially in the upper reaches, is then very considerable, and boats cannot work up-stream without some difficulty. But for the remaining eight months of the year, a smaller body of water is admitted from the river, and for half that period there is practically still water navigation. On the Ganges Canal, on the other hand, the principal demand for water is not during the rains, when the river could supply any quantity that might be required, but during the dry season. Rice is the great staple produce in the South of India, wheat that in the N. W. Provinces. The one is raised in the rains, the other in the dry season. The wheat crop on the Jumna Canals is greater than all the rain crops united. These canals have been in operation for many years, and rice cultivation has in no way been discouraged, unless near cantonments and large towns; yet it has not extended to such a degree as to require a greater supply of water than the wheat. The following figures which are taken from the last Report (for 1864-65) of the Chief Engineer, Irrigation Department, Punjab, serve to show the state of the Irrigation under the Western Jumna Canals.

Total number of acres irrigated during 1864-65, 434,965.

Area in acres of the principal crops irrigated for the last five years:—

	1860-61. (Famine year.)	1861-62.	1862-63.	1863-64.	1864-65.
Rice, ...	44,965	58,578	57,925	47,353	57,157
Cotton, ...	43,706	33,558	25,549	45,882	77,738
Sugar, ...	26,102	33,782	44,730	30,089	29,786
Wheat, ...	1,81,208	1,48,317	1,11,129	1,45,234	1,63,159
	2,95,971	2,74,235	2,39,333	2,68,558	3,27,840

The rice and cotton are rain, or "Khureef" crops. Wheat, dry weather crop, or "Rubbee:" the sugar is irrigated in both seasons.

The average monthly discharge of the canal was 1,784 cubic feet per second; 243 acres were therefore irrigated in 1864-65 by each cubic foot per second. The following was the discharge during the different months:—

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	Khureef.		Rubbee.
May, ...	250	November, ...	2481·8
June, ...	1985·2	December, ...	1717·5
July, ...	2431·80	January, ...	482·72
August, ...	1559·15	February, ...	1532·28
September, ...	2265	March, ...	1898·05
October, ...	2554	April, ...	2554
Average, ..	1791	Average, ..	1777

From the above it appears that the demand for water in April was as great as in July, and in December and March as in August, though July and August are months in which rice requires a plentiful supply of water.

Instead therefore of the demand for water being fluctuating as is the case in the Delta channels, it is nearly constant throughout the year, and an exceptionally high supply is not wanted owing to the rains; on the contrary, the maximum supply required is that yielded by the river during the dry season, and the current will have to be kept up at its maximum during the whole of the period, which on the Godavery and Kistna is available for still, or nearly still, water navigation.

J. C. A.

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No. CXXVIII.

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

(5TH ARTICLE.)

Compiled from the Annual Reports of the Surveyor General of India.
BY H. DUHAN, ESQ., *Personal Assistant to Surveyor General.*

SEASONS, 1859-62.

Kashmir Series.—The operations in Kashmir, under the superintendence of Captain Montgomerie made good progress, notwithstanding the increased difficulties which had to be encountered as the work progressed, and entered higher and more inhospitable ground. In the year 1861, the triangulation was extended over an area of more than 12,000 square miles, including some very elevated and difficult country in Zanskar, Rukshu, the Upper Indus, and in Khagan and Nubra. At several points it was carried up to the Chinese Boundary, and stations were visited in the neighbourhood of the Parang and Baralacha passes, where a junction of secondary points was formed with the North West Himalaya Series, the basis of the Degree sheets recently published in Calcutta by the Surveyor General. The stations in Ladak on the Upper Indus were very high, generally over 17,000 feet. Mr. Johnson took observations at one station more than 20,600 feet high, the greatest altitude yet attained as a station of observation. Several remarkable peaks Trans-Indus, probably forming the watershed between the Chitral and Swat Vallies, were fixed from the stations West of Khagan.

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THE TSO-MORARI L

Rupshu, Thibet.

Scale 4 Miles = 1 Inc

Surveyed by W. T[illegible]

UNIV. OF MICH.

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The Topography executed in 1861 comprised an area of about 14,500 square miles executed on the scale of 4 miles to the inch, leaving but a very small portion of Little Thibet unfinished, and completing the greater portion of Nubra, Ladak, Rupshu (or Rukshu) and Yanskar. Several of the Salt Lakes on the Table land of Rukshu were surveyed. Some exceedingly difficult ground was sketched by Captain Austen, in Little Thibet, varying in altitude from 7,000 to 28,300 feet above the sea. The glaciers he has discovered and surveyed are probably the largest in the world out of the Arctic regions, the Baltoro Glacier, in the Braldo branch of the Shigar Valley, being no less than 36 miles long. The Biafoganse is nearly as long, and forms, with the glacier on the Nuggair side, a continuous mass of ice nearly 64 miles in length. To delineate them properly a great amount of roughing and exertion, and not a little danger, had to be undergone by Captain Austen, as it was necessary for him to encamp on them for days, and to ascend to great heights on either side.

The carrying out of these interesting operations has involved vast labor and exposure. The country was found to be barren and desolate in the extreme, and the weather very unfavorable, in consequence of the extraordinary heavy rains, for which the year will probably be long remembered. Contrary to their wont, the clouds crossed over the south of the Himalayas to the Northern side, bringing heavy falls of snow in August, and generally hindering the work. Supplies and firewood had to be carried great distances, argols of yâk dung being often the only fuel available.

The Kashmir party being employed in mountains which are only accessible during the summer months, its field season is the period of recess of the Trigonometrical parties employed in ordinary districts. The usual Survey year commences in October, by which month the computations and maps of the preceding field season are generally brought up, and the party is ready to take the field again. The Kashmir Survey year is exceptional and commences in March. The Officers in charge of the various parties submit their respective annual Reports on the termination of the field operations, which are the real test of the advance made during the year.

The *Coast Series*,* between Calcutta and Madras was placed under

* On the Coast Series in 1860-61, the principal operations consist of 52 triangles, arranged so as to comprise one double and five single polygons, and one quadrilateral. 21 triangles were measured

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the Superintendence of Captain Basevi, Bengal Engineers, in the autumn of 1860; the exigencies of the Department having required his transfer from the Trans-Indus Frontier all the way to the Madras Coast. His operations commenced in the vicinity of Vizagapatam, and were proceeding towards Rajahmundry, when on approaching the hill of Kapa in the Rampa estate, he found that his signallers had been driven away from the hill with threats of violence, and that the inhabitants of the District were assembling to prevent him from ascending. The estate is rent free, and the people are a lawless set, though under the control of the Godaveri Magistracy. Captain Basevi, having obtained an extra Military Guard and a body of Police, made his way to the summit of the hill without molestation, and took the necessary observations. One day, the people set fire to the grass on the hill, which was about 8 feet high, and a Rajah brought intelligence that they were collecting to attack the Surveyors; but the fire was extinguished, and the attack was not attempted. Captain Basevi's chief apprehensions were for the signallers whom he had to leave behind at the station, but a guard was left with them, and they were unmolested. The only serious inconvenience occasioned was in having to construct the station on a block of laterite several feet below the hill, for the summit was covered with dense jungle which there was no means of clearing away without the assistance of the villagers, all of whom had absconded. Fortunately, such interruptions are of rare occurrence, only happening in the unusually lawless districts around Hyderabad.

The operations proceeded without further opposition or hindrance, except from the physical difficulties of the ground passed over. The district between the Godavery and Kishna Rivers was crossed, with considerable trouble, owing to the absence of high hills, and the undulating nature of the ground, which was all the more difficult because covered with dense jungle. Thus the selection of stations in such a manner as to form an unbroken chain of quadrilaterals and polygons, became a very tedious and laborious undertaking, involving the repeated rejection of positions which at first promised the requisite visibility in all directions, but were afterwards found to be deficient in some essen-

during the first season, with a 2-foot Theodolite by Barrow, giving a mean triangular error of 0·65″, and an equal number measured the next season, with a similar instrument by Throughton and Simms, gave a mean error of 0·37″. Azimuthal observations on Circumpolar Stars were taken at three stations.

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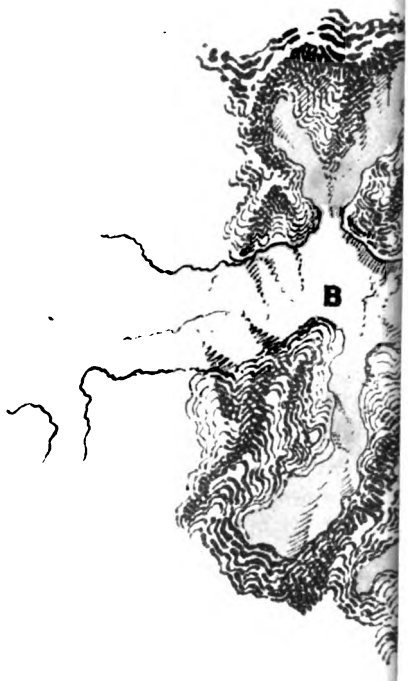

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tial relation. Nevertheless, in the two field seasons the principal triangulation was carried a distance of upwards of 180 miles, reaching a point in the Guntoor district near the meridian of Madras, whence it was afterwards connected with the meridional arc between Jubbulpore and Madras, to be extended Southwards into Ceylon.

Great Indus Series.—These important operations were happily completed during the season of 1860-61. Major Walker superintended the triangulation as well as the levelling operations from the sea at Karachí to the Chuch Base Line near Attock, comprising two parties for triangulating the northern and southern sections of the Indus Series respectively, under Lieuts. Basevi and Mr. Keelan; and two parties for the levelling operations. After satisfying himself that the triangulation was proceeding satisfactorily, Major Walker was personally engaged in carrying a line of levels from Masee Pir in Upper Sind to the sea at Karachí, which he accomplished in time to accompany (at the request of the Lieutenant Governor of the Punjab) the expedition under Brigadier General Chamberlain, C.B., against the Mahsood Waziris, and make a survey of the invaded territories with the assistance of Lieuts. Basevi and Branfill.

Sutlej Series.—On the completion of the Indus Series, as above noticed, the Surveyor General decided on carrying an oblique series along the South East Bank of the Sutlej, from Mittunkote to Ferozepore, to tie up the Punjab Meridional series, and form a basis for future triangulation into the deserts of Sind and Rajpootana. Certain small portions of the Indus triangulation which had been executed with a 2-foot theodolite gave unusually large re-entering errors. Lieutenants Herschel and Thuillier, both of the Bengal Engineers, and first Assistants of the G. T. Survey, were consequently sent to revise them with the Great Theodolite, while Mr. Armstrong was selecting Stations and building Towers on the line of the Sutlej. Twenty-one principal triangles were ably and rapidly revised, after which Lieut. Thuillier proceeded to join the Kashmir party, while Lieut. Herschel took in hand the Sutlej Triangulation. This consists of a Series of single triangles, of which one flank rests on the sand hills fringing the Bahawulpore desert, and the other in the lowlands which are periodically inundated by the Sutlej. Thus the greater portion of the rays traverse moist jungles of tamarisk and long grass, alternating with ridges of

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sand, forming a combination which is peculiarly troublesome in disturbing the atmosphere, and causing lateral refractions to perplex and weary the observer and impair his measures. The principal operations consist of 38 triangles, extending over a distance of 132 miles, from a side of the Indus Series below Mittunkote to the vicinity of Pak Puttun. Being entirely in the plains they cover an area of only 1,960 miles.

Lieutenant Herschel took astronomical observations for the direct determination of azimuth at 9 stations, at an average distance of 72 miles apart. His mean triangular error was 0·53″. In 85 angles his mean probability of error was 0·25, between extremes of 0·10 and 0·38.

Lieutenant Herschel introduced an improvement in the referring marks hitherto used in the Survey. Instead of having two apertures—one for a lamp, the other for a heliotrope—he made both lamp and heliotrope illuminate the same piece of ground glass, the aperture of which was limited by a circular diaphragm, of diameter suitable to the distance. Thus one object is intersected instead of two, and there is no flickering or unsteadiness of signal from wind or imperfect direction of heliotrope; there is no dazzle from too bright a sun, nor total disappearance in its absence, for the mere reflection of the sky suffices to illuminate the glass in tolerably clear weather. One mile is considered the best distance for such a mark.

The *Rahoon Meridional Series*,* under the charge of H. Keelan, Esq., 1st Assistant, G. T. Survey, advanced a distance of 176 miles, by 33 Principal Triangles, arranged in quadrilaterals and hexagons, covering an area of 4,130 square miles. It laid down portions of Jeypoor, Ulwar, Doeli, Boondi, and numerous other places of importance. The published charts of the Kotah and Boondi territories indicate a succession of hills over which it was supposed that the triangulation might have been carried and completed last season. But the ground was found to be the very reverse of what had been expected, and to require the construction of Towers, thereby protracting the operations into another season.

* Mr. Keelan employed Colonel Waugh's 2-foot Theodolite, No. 1, in his triangulation. The average error of his 33 triangles is 0·36″. The mean probability of angular error is 0·30, between extremes of 0·12, and 0·65. Azimuth observations were taken at three stations. The secondary triangulation covers an area of 7,040 square miles.

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The *Goorhagurh Meridional Series*,*—under the charge of Geo. Shelverton, Esq., Civil 2nd Assistant, G. T. Survey, traverses a meridian close to that of Umritsur, and was brought to a termination in 1861 by joining the Arumlia Series, which had some years previously been carried by Captain Rivers of the Bombay Engineers, up an adjacent meridian as far as Ajmeer, from the Great Longitudinal triangulation. From Sirsa to Ajmeer it crosses a desert tract, of which Mr. Shelverton reports that, "the main difficulties encountered were scarcity of water, of building material, of laborers and of provisions—the country traversed had suffered for three years from extreme drought; large villages originally containing upwards of 500 families had been deserted by all except first class farmers, who were too proud to work. Wholesome water was scarcely procurable, and water even for building purposes had frequently to be conveyed from distances of 4 and 5 miles. The large reservoirs of water upon which the inhabitants depended for their supply during the greater part of the year had invariably been exhausted, and the expensive kucha wells of the country barely sufficed for local wants. It was therefore under very adverse circumstances that the Goorhagurh Meridional series was conducted during the field season of 1860-61.

During the following season the deserts of Bikaneer, Shekhawati and Marwar were extensively traversed, and a very large area of both principal and secondary triangulation was executed, reflecting much credit on Mr. Shelverton and his Assistants, who skilfully and energetically availed themselves of the facilities offered by mounds and hills, commanding extensive prospects, to fix a large number of positions of importance. In the two seasons the triangulation was carried a direct distance of 342 miles by 50 consecutive triangles, covering an area of 4,454 square miles.

The *Assam Party*, in charge of C. Lane, Esquire, Chief Civil Assistant, was employed in 1860-61, in triangulating along the Eastern Frontier, from the south of Gowhatty to Cherra Poonjee. Recent prohibitions regarding the impressment of coolies occasioned much em-

* Mr. Shelverton employed Colonel Waugh's 2-foot Theodolite, No. 2, in his triangulation. The average error of his 50 triangles is 0·54″. The mean probability of angular error is 0·46 between extremes of 0·18 and 0·87. Azimuth observations were taken at only one station. The secondary triangulation covers an area of 10,954 square miles. Owing to the paucity of good natural or artificial objects, 152 secondary station marks were built for future reference.

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barrassment, notwithstanding that the majority of the Cossyahs are porters by trade; delay was thus caused in taking the field, and often afterwards. The operations were further impeded by clouds and mists, and latterly by storms of such severity that on one occasion the whole of the Bunder bazar, on the bank of the Soorma, was utterly destroyed and no vestige left. Final observations were taken for 19 principal triangles arranged in a double series, extending over a direct distance of 62 miles, and covering an area of 1,207 square miles. Eight important snowy peaks of the Bhotan Himalayas were fixed.

During 1861-62, Mr. Lane was absent owing to illness, when his place was ably filled by Mr. W. C. Rossenrode, who extended the triangulation a direct distance of 89 miles eastwards through Cachar towards Munnipoor, and 25 miles southwards towards Independent Tipperah, in all 114 miles by 30 triangles arranged in a double series covering an area of 2,024 square miles. Some of the stations were situated in the Jynteeapore district, but the observations at them were fortunately completed before the rebellion broke out. Reciprocal observations had still to be taken to them from other stations around, necessitating the employment of Hindoostani clashees to work the signals on them; the men, though robbed and threatened, maintained their posts during the rebellion, and only came away when signalled to do so at the termination of the observations.

The *Bombay Party*,* under the superintendence of Lieutenant, now Captain, C. T. Haig, Bombay Engineers, 1st Assistant, was engaged in 1860-61 in completing the triangulation necessary to connect the Guzerat longitudinal series, on the parallel of 23°, with the Singi meridional series, which had been brought up from Bombay as far as Surat, by Captain Rivers, some years previously. The connexion was satisfactorily accomplished, notwithstanding that the section of the party

* Astronomical observations for azimuth were taken at two stations. Of the Meridional Series, south of Oodipoor, Captain Haig reports as follows :—"The country through which this series runs is inhabited by the wildest set of savages that I have as yet ever had to do with. The thieves (who form a portion of the inhabitants of every village) for the sake of the clothes a man has on his back, assault him; if he attempts to escape, they bring him down with a shower of arrows, utterly regardless of his life. On this account, communication by messengers was attended with great risk, and consequently Messrs. Da Costa and McGill were each unacquainted with the other's progress until they actually met, otherwise I had intended them to be in frequent communication. It is partly due to this that the Series has a bend in the centre, and partly because the Raja of Salcomber, a very refractory chief, would not permit a Station to be built on his hill, although directed to do so by the Political Agent."

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employed in selecting stations, got entangled in some malarious jungles, where both Europeans and Natives were attacked with jungle fever, and had to retire to Broach until the sickly season was over. In 1861-62, the Guzerat Longitudinal series was extended eastwards to the Khanpisura series on the meridian of 75°, and a series of triangles on the meridian of Oodeypore was carried between it and the Karrachí Longitudinal, thus completing the triangulation of the northern portion of the Bombay Presidency. The principal operations involve 126 miles of triangles arranged in a double series, and about 190 miles arranged singly, the total number of triangles being 42, covering an area of 7,450 square miles.

Hydrabad Topographical Survey.—The party was employed this season in triangulating the tract situated between the western boundary of Baitool, Ashti, Dhar, Narnala, Mailghat, and Jilpi Amner, near the Taptee, embracing altogether about 3,000 square miles, the northern portion of which is covered with heavy forest, poorly populated, and exceedingly unhealthy. In addition to the above, a party was employed in extending a minor series of triangles based upon the great arc side, "Badaili to Budgaon," to assist in connecting Major Brown's survey with the north and west portion of that completed during the seasons 1856-57 and 1857-58, embracing about 1,500 square miles. Cholera having broken out, the work was much retarded; notwithstanding this and the general unhealthiness of the season, a large quantity of work both in triangulation and topographical detail was executed by Mr. Mulheran and his Assistants. Credit is due to Mr. Mulheran for the successful introduction of Native Agency into this branch of the operations.

Ganjam Topographical Survey.—No. 1 party was employed in the Khond Hills of Goomsoor and the neighbouring country. Captain Saxton conducted the laying out and observing of a principal series of triangles, filled in with numerous secondary points, and re-entering on several stations of the previous season's secondary operations, which agreed extremely well in azimuths, latitudes, longitudes and heights. All the other members of the party were employed in plane tabling, and surveyed 2,000 square miles.

No. 2 party was employed under Mr. Nicolson in the survey of a portion of Cuttack, and the South West Provinces; while the triangul-

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ation was advanced from a side of the Ganjam Series. The area surveyed in detail on the scale of one mile to one inch was 2,320 square miles, and the style of mapping was in advance if any former year. Mr. Nicolson likewise triangulated 2,300 square miles of country.

The *Levelling Operations*,* under Captain Branfill, of the late 5th Bengal European Cavalry, 2nd Assistant, made good progress, having in the two field seasons been carried from a point near Mittunkote, on the Indus line of Levels, to the Dehra Dhoon Base line *viâ* Bahawulpore, Ferozepore, Loodiana, Umballa, and Saharunpoor, and thence on to the Sironje Base line in Central India, *viâ* Meerut, Allygurh and Gwalior, over a distance of 999 miles. In the course of these operations, stone Bench-marks were fixed at distances of 12 to 15 miles, and the most substantial milestones met with by the road side were also determined, for future reference by Canal or other Engineers engaged in levelling operations. A satisfactory connexion was made with the Ganges, and the Eastern Jumna Canal levels, and those of the Allahabad and Agra Railway, which are now capable of being reduced to the mean sea level as a common datum.

The *Computing Office* in Calcutta, under the Superintendence of Baboo Radanath, chief computer, was engaged in completing the triplicate manuscript volumes of the General Reports of the Parisnath, Hurilong and Chendwar Meridional series, and in furnishing elements for the various Topographical and Revenue Survey parties requiring them. In March last, Baboo Radanath retired on a pension, after 30

* During the course of the levelling operations, it has often been noticed that though the independent results obtained at each station by the respective observers differ if at all by almost imperceptibly minute quantities, the differences have a tendency to go one way, and have occasionally accumulated to large amounts. On this curious and perplexing subject, Captain Branfill reports as follows: "I think we can all subscribe to the following facts—The state of the weather and the season of the year have a very considerable effect on our results, as shown by the difference between observers. We have found that the apparent law of our differences is least developed some time in the middle of the cold season. In a run of bad weather (*i. e.*, bad for the work) the apparent law of our difference is for the most part marked when the atmosphere is clearest, and when we have supposed our observations to be freest from error; and conversely in a run of good weather, when the air is hazy from smoke or dust, or greatly agitated by wind, and in short, when we have found most difficulty in reading the staves, our results have most coincided with each other. Our differences do not appear to vary with the distances of the staves. On the contrary the differences are perhaps even more marked as the day grows older, and the distances of the staves from the instrument are reduced. The general direction in azimuth of the line of our work has some connection with the cumulative differences, and we have noticed that the tendency to differ is more marked when proceeding *towards* a certain point of the compass, than when proceeding *from* that point towards its opposite."

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years' service, during which he had repeatedly earned the approbation of the successive Surveyors General under whom he had served. On his resignation it was deemed advisable to remove the computing office from Calcutta to the Head-quarters of the Trigonometrical Survey at Dehra Dhoon, to bring it into more direct connexion with the Superintendent of the Department, and also with the field parties whose computations it has revised and collated.

The *Drawing Office*, under superintendence of W. H. Scott, Esq., Civil Assistant, G. T. Survey, was chiefly employed in compiling Maps of Kashmir and Ladak, from the plane table sheets sent in by Captain Montgomerie. The first of these large maps was transmitted to the Home Government, the second was well advanced. Ten original preliminary charts of the Triangulation in different parts of India were forwarded for the use of the Surveyor General's Office, and duplicates prepared for the Geographer to the Secretary of State for India. Triplicate charts were also constructed for the manuscript volumes of the General Report.

Between the completion of a Survey, in this country, and its publication, a long interval invariably elapses, during which even the Supreme and Local Governments are without access to valuable information, acquired but unimpartible, because of the costliness of manuscript maps and the time occupied in their construction. An attempt was therefore made to employ photography for making rapid copies of maps and charts, as a temporary substitute for the final engravings. This process has of late year been extensively adopted in the Ordnance Survey of Great Britain for reducing maps, as a substitute for the pentagraph, and two complete sets of photographic apparatus were sent out to this country by the Secretary of State for India, for similar employment. The operation was by no means easy, for the apparatus had to be specially adapted to make full scale copies, and not reductions merely, for which it was originally intended, and the maps required to be drawn with special reference to future copying or reducing by photography. An ordinary finished map cannot be reduced without a large portion of the names becoming too microscopic to be easily legible. In the first Kashmir Map the rivers were colored in blue, and the broken land and low hills in red, the higher ranges being in Indian ink. Consequently a photograph of it would show no

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rivers, and would invert the depth of shading of the high and low hills, bringing the latter into excessive prominence.

Captain Melville, who has already been mentioned in connexion with the Topographical Survey of Kashmir, attained considerable skill as a photographer, and succeeded in making an excellent reduction to half scale of the second Kashmir Map, before any names were printed on it. The names were afterwards inserted by hand, and were then copied to full scale, and afterwards printed for circulation.

After a continuous service of 32 years, during 17 of which he Superintended this extensive and important Scientific Department, Sir Andrew Waugh retired from the service, concluding his administration with the following remarks:—

"In the progress of the survey in various parts of India, during the period I have commanded the Department, many instances have occurred in which the skill, endurance and resources of my officers have been severely taxed, and in which obstacles—physical, social and climatic—have been overcome, in a style, which if known, would justly entitle those who have been employed in such arduous works, to the applause which is conceded to the highest triumphs of British energy. The almost impassable barriers of the greatest mountain range in the world, covered with perennial snow, have been unable to check the progress of our operations; for the Himalaya has been crossed and re-crossed, and our stations planted on peaks never before trodden by the foot of man; the swampy morasses and deadly forests, in several parts of India, have been traversed, and many tracts of hilly country covered by primeval jungles, scarcely inhabited by human beings, and forming almost *terræ incognitæ*, have been covered by our stations. The Little Desert has been crossed by our triangulation, and several chains of great length have been carried across the Runn and its conterminous tracts, uniting among themselves the worst features of the desert and swampy morasses and jungles of other parts of India. All these undertakings have been arduous in the extreme, and have been achieved with small numbers and most inadequate means.

"The accuracy and precision which have characterized the Geodetical operations, the extraordinary excellence of the Levelling, and the beauty and fidelity of the Topographical delineations, are the best

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criterions of the professional merits of the members of the Survey Department in all its branches; while the compilations in office, the Lithographic publications, the labors of the computers, and the skilful work of the Mathematical Instrument Department, are equally deserving of praise, and render it necessary that I should express my obligations to all who have shared in the work, in the field or office.

"From my subordinates, in every grade, with whom I have been associated, and to whom I am so largely indebted for the success that has rewarded my labors in the Department, I have always received the most willing and able assistance in every branch of the work. Their cheerful enterprize and manly endurance have been conspicuous on every occasion; and a more able, reliable, and loyal body of gentlemen does not exist in Her Majesty's Service in any part of the world."

Sir Andrew Waugh was succeeded by Major (now Lieut.-Colonel) J. T. Walker, R.E., as Superintendent of the Great Trigonometrical Survey, and by Lieut.-Colonel Thullier, R.A., as Surveyor General of India.

NOTE BY EDITOR.

This History, having been brought up to the date of the Surveyor General's Annual Reports, which are now regularly published, and of which that for 1862-63 has already appeared in the 1st Vol. of these papers, will for the present be concluded.

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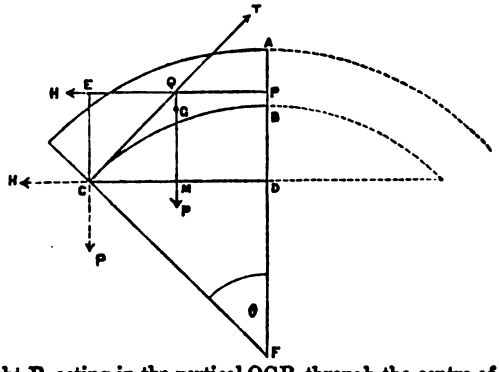
Correspondence.

THE Editor acknowledges with thanks the receipt of the following papers:—The Tonse Bridge—Fort William Water Supply—Theory of the Arch—Railways in War—Rajpootana Road Specifications—Masonry Arched Ribs for Bridges—Road Tracing in South Canara—The Bombay Revenue Survey.

ON IRON TIE-BARS FOR ROOFS.

To the Editor.

DEAR SIR,—My attention has been arrested by a paper in your last Number, on Iron Tie-bars for Roofs, in which the singular result is obtained that the horizontal thrust is greatest when the length of the circular arch is zero. It is clear that the fallacy lies in the assumption, that T, the re-action at C, the spring of the arch, *acts in the tangent* to CB. This must not be assumed; as the following calculation will show:—



The half-arch AC, is maintained in equilibrium by three forces; viz. (1) its weight P, acting in the vertical QGP, through the centre of gravity G; (2) a horizontal thrust H, acting, at some point P, in the line AB which devides the arch into two equal parts, in the direction PQH, cutting the vertical in which P acts in some point Q; this horizontal thrust is the *resultant* of the horizontal pressures of the several elementary portions of the joint AB against each other; (3) the re-action T at the spring of the arch C. As there is equilibrium, the direction of this force T must pass through Q.

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The position of the point P is not known, further than that it lies between A and B. It will be different for different lengths of the arch, and therefore BP is some unknown function of θ. Here, then, ambiguity enters the problem to be solved, at the very beginning.

Let FA $= a$, FB $= b$, BP $= z$.

Taking the moments of the forces about the point C, we have

H.CE = P.CM or H $(z + b \text{ vers } \theta)$ = P. (CD − MD) = P. $b \sin \theta$ − P.MD.

If w is the weight of a horizontal prism of the materials of the arch, its length being the width of the bridge, and its vertical section being a square unit, then P = $\frac{1}{2} w \theta (a^2 - b^2)$, and by the process of obtaining the centre of gravity by the Differential Calculus—

$$\text{P.MD} = \frac{1}{3} w (1 - \cos \theta)(a^3 - b^3).$$

$$\therefore \text{H}(z + b \text{ vers } \theta) = \frac{w}{2} b (a^2 - b^2) \left(\theta \sin \theta - \frac{2}{3} (1 - \cos \theta) \frac{a^3 - b^3}{a^2 b - b^3} \right)$$

(I would here observe that when $\theta = 0$, this formula makes H = 0, as it should do).

Put $\frac{2}{3} \frac{a^3 - b^3}{a^2 b - b^3} = \text{N}$, and $z = b.x$; it is not difficult to show that N is always greater than unity; the quantity to be made a maximum is—

$$u = \frac{\theta \sin \theta - (1 - \cos \theta) \text{N}}{x + 1 - \cos \theta}$$

As x is an unknown function of θ, we cannot differentiate this; and the solution of the problem is impracticable.

I will take the following extreme case. Suppose the horizontal thrust so great, that the point C is on the verge of moving to the left, the arch of sinking at A, and therefore the joint AB of opening at B. In this case P will be at A; or $x = a - b$; and $x = n - 1$, if $a = n.b$: then also $\text{N} = \frac{2}{3} \frac{n^3 - 1}{n^2 - 1} = \frac{2}{3} \frac{n^2 + n + 1}{n + 1}$; n is always greater than 1; and

$$u = \frac{\theta \sin \theta - (1 - \cos \theta) \text{N}}{n - \cos \theta}.$$

The usual method of the Differential Calculus will lead to an equation very difficult to solve even by approximation. The following course may be pursued. Having determined the numerical values of n and N, substitute them in u. Then tabulate the values of u for successive values of θ, viz,. 10°, 20°, 30°, ... 90°, till the values begin to diminish, which will show between which pair of values of θ the maximum lies. Then approximate still further to θ, by tabulating the values of u for values lying between those limited and differing by 1°. In this way we may find for what value of θ the arch, on the point of sinking at the crown, will have the greatest horizontal thrust. If the strength of the tie-rod is sufficient to resist this, it will be sufficient to resist all other thrusts.

J. H. P.

CENTRAL INDIA,
January, 25*th*, 1866.

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Correspondence.

THE Editor acknowledges, with thanks, the receipt of the following papers:—Pendulum Operations of the G. T. Survey—The Double Island Lighthouse—Velocity and Surface Slope of Canals—Glazed Tiles for Roofs—Presbyterian Church, Allahabad—Remedy against White Ants—Breach of the Coleroon Anicut—The Sholapore Tank—Memo. on the Markunda Bridge—Report on the Hastings Shoal.

ON IRON TIE-BARS FOR ROOFS.

To the Editor.

SIR,—I have worked out A's case, in No. IX. Vol. II., of the Professional Papers. Roof 24 feet span, 6 feet rise, and 6 inches thick; weight of material, 180 lbs.

The maximum horizontal thrust for the case of rotation is 993 lbs., for the case of sliding 365 lbs., per foot run of roof.

The point of maximum thrust or joint of rupture is 12¼ degrees above springing level—this is where A should put his tie-rods—and up to this point he must build his backing.

He might reduce the diameter of his tie-rods to ¾-inch with perfect safety.

The pressure on the joint will not exceed 23 lbs. per square inch.

I should mention that in working out the above I used Petit's Formulæ and Tables, the general method being the same as that given by J. H. P.

Yours faithfully,
A. J. H.

GHURWAL,
6th March, 1866.

THE "COMPTAGE AMBULANT."

DEAR SIR,—It seems to me that, in the calculation of the "Comptage Ambulant," in page 68, of Vol. III., Mr. Hughes has just reversed the position of the *minus* quantity, and that the rule ought to be—

When the traffic is the same up and down the road, it equals the number of carts

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met by the observer, added to the number of carts which pass him, but diminished by the number of carts which he *overtakes*.

Take an example:—

Suppose the traffic equal up and down, and that it is 20 carts each way in an hour, all going at the rate of 4 miles per hour = that is, a total of 40 carts. And suppose the observer's rate of progress is 2 miles per hour.

The observer takes a walk of 2 miles from A to B, and as soon as he leaves A, carts begin to *pass* him which left A when he did; and he *meets* carts which left B half an hour before. When he reaches B the last cart *passes* him which left A half an hour before, which is half an hour after he started.

That is, he meets the carts of 1½ hour, ... = 30
And the carts of half an hour pass him, ... = 10

Total, ... 40

Again—

Suppose his rate of progress to be 8 miles per hour. He walks from A to B in a quarter of an hour, and *overtakes* carts which started a quarter of an hour before him whereas he meets carts which started from B half an hour before him.

That is, he meets the carts of three quarters of an hour, ... = 15
Deduct the carts of a quarter of an hour which he *overtakes*, = 5

Total carts in a quarter of an hour, the time he took to go from A to B, ... 10

That is again—40 carts per hour.

Yours faithfully,
W. J. L.

April 25th, 1866.

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Correspondence.

THE Editor acknowledges, with thanks, the receipt of the following papers:—The Aden Tanks—Roads in Coorg—The Hurroo Bridge—Breach of the Coleroon Anicut—Manufacture of Irrigation Pipes—Practical Suggestions in Road-making—River Works on the Gogra—Karwar Harbour Works—Waterway of the Sye Bridge.

IRON TIE-BARS FOR ROOFS.

To the Editor.

DEAR SIR,—Could you find room in your next issue for the following remarks in reply to J. H. P.'s letter in No. 10.

1. It does not seem to me to be singular that the value $\theta = 0$, should give the maximum horizontal thrust. It merely shows that the horizontal thrust, expressed as a function of the variable θ, is a maximum when $\theta = 0$; or in other language, that the point of rupture is at the crown.

2. I do not take friction into account any more than J. H. P. does cohesion. It follows necessarily from this, that the resultant of the two forces applied to the half arch (its own weight and the horizontal thrust) must act at right angles to the joint. For if it did not, the resultant could be resolved into two forces—one acting in the direction of the tangent would be supported y the reaction of the joint; the other parallel to the joint, unless counteracted by friction (which I do not take into consideration), would cause the failure of the arch by sliding along the polished voussoir.

3. Rankine (Applied Mechanics, page 204) determines the horizontal thrust exactly as I have done. He says: "*when the point of rupture is the crown of the arch . . . . . it has already been shown that . . . .*

$$H_o = p_o \cdot r_o .$$

p_o. being the intensity of the vertical load, and r_o the radius of curvature."

I obtain the same result by finding the value of the resulting vanishing fraction. But the principle is exactly the same; and if Rankine is wrong, I am quite content to be wrong also.

4. J. H. P.'s Formula (although no doubt perfectly correct on the supposition that the arch turns on the edges of the voussoirs) is quite inapplicable in practice, from the enormous labor of calculation it entails. Petit has calculated Tables for J. H. P.'s formula, by means of which I have been able to compare his results with mine; and in every case my formula gives the safer result. These Tables of Petit are now very scarce, and without them J. H. P.'s formula is useless.

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5. My formula is as mathematically correct as J. H. P.'s ; and has the great advantage of giving a safer result, and of being readily applicable in practice.

6. Should you wish it,* I can give you a comparative statement of the results of the two formulæ, as applied to roofs as usually constructed.

Yours truly,

CAMP, BAGNEE, 1*st* May, 1866. A.

The above was accidentally delayed in transit.—[ED.]

THE "COMPTAGE AMBULANT."

SIR,—Your correspondent, in the last number of Professional Papers, is perfectly right.

The mistake, a clerical error, occurs in putting the formula $C = O + M' - M''$ into words.

When printing the errata to this volume, will you kindly enter at page 69, line 5; *read*, "That when the traffic is the same up and down the road, it is equal to the number of carts met by the observer going in his opposite direction, added to the number which pass him going in the same direction and diminished by the number of carts going in the same direction which he passes:" *instead of*, "That when the traffic is the same up and down the road, it is equal to the number of carts met by the observer going in his opposite direction, added to the number he passes going in the same direction, and diminished by the number of carts going in the same direction which pass him.

W. J. L.'s letter affords numerical proof of the correctness of the formula.

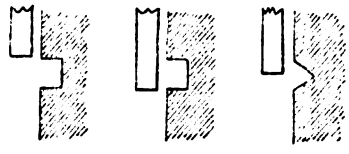
Yours faithfully,

A. J. HUGHES.

HIMALAYA CLUB, 29*th June*, 1866.

NOTES ON LEVELLING.

DEAR SIR,—K. C. L. in his excellent remarks on Levelling and Bench-marks in your February number, recommends the broad arrow and bar used by the Ordnance Survey,



but he does not state what portion of the horizontal bar forms the bench-mark. The groove or bar is perhaps half an inch to an inch wide, and the marginal sketches show that there are three distinct positions in which the bottom of the staff may be held, making a considerable difference in its level. It would therefore add much to the value of K. C. L.'s paper if he would clear up the point.

Yours truly,

W. H. M.

8*th May*, 1866.

* Yes; let us have it.—[ED.]

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A SUGGESTION.

MY DEAR SIR,—There are few men in the P. W. Department who have not, at some time or other, suffered in taking over a new division, from the difficulty of finding out the previous history of the large works which have been some time in hand. The relieved officer's Memo. of works in hand is seldom of much use, except for just the current arrangements.

In my own case, I have just taken over a division in which there are several heavy works, about which correspondence has been going on for very many years, and actual work some five or six years. Alterations have been now and again ordered, and many revised estimates submitted, and generally each work has been carried on on the *coming* estimate, so that no one specification has been followed throughout. Just lately some peculiar departures from my specification have come to light, and down comes Government and calls out, who did this, and why did he do it? Now, to make myself acquainted with the works, and answer such questions as the above, I have to hunt up correspondence and progress reports for many years, and then I can't do it. I shall leave the division again soon, and my successor will have all the trouble over again.

Now all this trouble and confusion might be remedied, and also any unauthorised departure from sanctioned specification much checked, if every Executive Engineer had to keep a running note or precis of all correspondence on all large works separate for each, in something like the accompanying form.

ABSTRACT OF CORRESPONDENCE, &C., ON_____

Letters received and despatched.				Abstract of Contents.	Contemporary memo. of state of work, orders issued, accidents, &c., &c.
Date.	No.	From	To		

The posting up should be done, I think, by the Executive Engineer himself, and he should enter a work in the book when it had been six months, say, under discussion, posting up the back six months at once.

I think the advantage of such a record to every one concerned, will be readily allowed, and I don't think the labor would be a heavy addition to any one. Superintending Engineers would for their own interest see that it was kept up, and each Executive might feel that others were doing the same, so that he would get the benefit when he exchanged. Perhaps some of your correspondents might improve on my idea, and suggest how it could be brought into practice.

Yours sincerely,

A. M. B.

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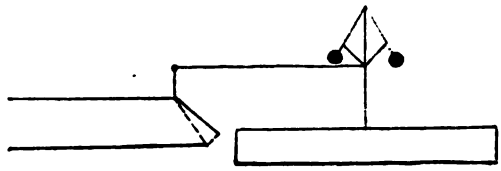
To the Editor.

SIR,—An idea struck me a day or two ago that a uniform discharge, through a pipe with varying heads of water, might be obtained by means of a small water-wheel (driven by the water as it issues through the valve), driving a governor exactly the same as a steam engine governor,



so that the lower the velocity of the water the larger the orifice would be, and the greater the velocity the smaller the orifice. Will you favor me with your opinion as to whether it would be of any practical value or not?

Your obedient servant,

H. H.

Make up a model and try it. The difficulty attending the solution of this problem lies in the practical working: simplicity of construction is a *sine quâ non*.—[ED.]

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Correspondence.

THE Editor acknowledges, with thanks, the receipt of the following papers:—The Drainage of Madras—Improvement of River Navigation—Public Works in Berar—Breach of the Krishna Anicut—Church at Steamer Point, Aden—Lakh Irrigation Project—Poona and Kirkee Water-Supply—Irrigation in the South Mahratta Country.

A SUGGESTION.

DEAR SIR,—In reading a suggestion by A. M. B. in the correspondence attached to the last number of the Professional Papers, it struck me that it would be preferable to bind the Correspondence with the Estimates in blank covers.

It seldom happens that large works are carried out as originally designed and estimated; and the advantage of this system is, that an officer carrying out a large work, has all the most important correspondence from the beginning up to date, and there is no necessity for referring to "files" for a letter required to serve a particular purpose. I would only bind such letters as convey suggestions for deviating from the original plans and specification, reports on unusual occurrences, or difficulties in carrying on the works, revised estimates, and the orders received from Government. A note in the column "remarks," in the abstracts of letters "received and despatched" would at once show where the letters missed from their proper places in the "files," are to be found.

I am now doing this for my own convenience, and if relieved before the work I have in hand is finished, the relieving officer will have everything at his finger ends.

CAMP, KOTE,
15th September, 1866. A. C. C.

IRON TIE-BARS FOR ROOFS.

SIR,—Being much interested in the discussion which has arisen regarding tie-bars for roofs, on account of its relation to my theory of arches, I beg to offer a few remarks on the subject.

Your correspondent "A" appears to have fallen into a serious error, in regarding the horizontal thrust of such arched roofs as a variable quantity. It ought not to

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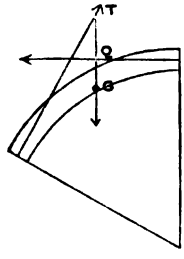
be necessary to prove that this is a constant, but that there may be no doubt I quote from Rankine, "The principles * * * are applicable to linear arches under *vertical loads;* and in such arches, the quantity denoted by H in the formulæ is a *constant thrust,* in a direction perpendicular to that of the load." [*Civil Engineering,* 1864, p. 203.] But "A" must regard it as a variable force, because he says, "there must be some point at which the expression P cot θ is a maximum," and this is the value which he gives for H, or the horizontal thrust [*Professional Papers,* November, 1865.] He makes this statement, apparently, on account of the variable factor cot θ, and accordingly he finds the maximum value of H when $\theta = 0$, and cot $\theta = \infty$. But the necessity that P cot θ should have a maximum value does not exist, for P is also variable; and the product of two variables may be a constant, as for instance $x y = a^2$. And this is exactly what would occur in an arch built according to my theory, and not intended to carry any moving load.

But the arch on which "A" reasons is not so designed, for it is assumed to be of equal thickness throughout. I shall therefore proceed to show, that in this case also, we may not infer that the horizontal thrust must have a maximum value. For the expression $H = \cot \theta$ is true of one case only, viz. that in which the line of pressure is a circle, concentric with the arch. And if the thickness of the arch be uniform, the line of pressure is not a circle, but a line of varying curvature, to which the formula does not apply, unless we measure the angle θ at the centre of curvature, which is very different from the centre of the arch.

"A" has also fallen into another error, in regard to the three forces by which the semi-arch is held in position. He knows that one is vertical, and another horizontal, and he assumes that the third is at right angles to the joint under consideration. But he over-looks the fact, that three such forces in an arch of uniform thickness would not produce equilibrium at all, for which it is necessary that one must be equal and opposite to the resultant of the other two. This is noticed by "J. H. P." in his letter [*Professional Papers,* February, 1866.] "As there is equilibrium, the direction of this force T must pass through Q."



The way in which I should apply my theory, to determine the strain on the tie-bar is as follows:—

I know that when the line of pressure is a circle, the horizontal thrust is ten times the weight of a portion of the structure at the crown of the arch, the length of which is $\frac{1}{10}$ of the radius of the line of pressure. For in Table III. *Professional Papers,* August, 1866, which is perfectly general in its application, making R = 1 and H = 0·1, I found $Pm = 0{\cdot}0050$ where Pm was half the weight of the vertical block of the crown. Therefore $H = 10\left(\frac{1}{10}R \times z \times w\right) = Rzw$, where R = radius of Line of Pressure. Then asuming that the Line of Pressure is a circle passing through the middle of the arch-ring, I get $R = r \times \frac{z}{2}$; and therefore $H = \frac{w}{2}[2rz + z^2]$ which is "A's" formula. Lastly, because I know that the Line of Pressure is not really a circle, I should enquire whether the value thus obtained be more or less than the true horizontal thrust. And because it would become a circle by adding

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weight on the haunches, which would increase the horizontal thrust, I find that the calculated value is *greater* than the actual, and may be used with confidence to determine the strength of tie-bar.

The formula $H = P \cot \theta$ is perfectly correct for an arch theoretically balanced; in which the Line of Pressure is a circle, concentric with the arch. And for any small arc near the crown, the weight is the same whether the arch be theoretically balanced or not. Hence "A" gets a correct value, from the arch of equal thickness, by taking $\theta =$ an infinitesimally small arc, and I get practically the same, from the theoretically balanced arch, by taking $\sin \theta = \frac{1}{10} R$, (where $\theta = 5° 44'$). But the value which we thus obtain for H is strictly true only of an arch theoretically balanced, and is not strictly true of an arch of equal thickness throughout.

I observe that your correspondent "A. J H." (in the issue of May), writing on this subject says: "The point of maximum thrust, or joint of rupture is 12½ degrees above springing level—this is where "A" should put his tie-rods, and up to this point he must build his backing." But the tie-rods are not introduced for the purpose of preventing the *arch* from changing its shape. This is certain, because if the abutments were immoveable, tie-rods would be unnecessary. They are required to prevent the *abutments* from moving, these being only thin walls, wanting in stability sufficient to resist the horizontal thrust of the arch. Therefore the tie-rods must be put at the level of springing, and nowhere else, to be used to the best advantage. If they were placed 12½ degrees above this, they would afford no security against the failure of the roof.

ALEXANDER H. MACNAIR.

20th August, 1866.

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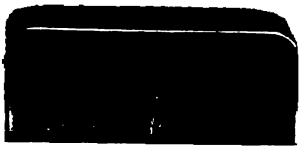

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